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Abstract

The use of toughened matrix composite materials offers an attractive solution to the problem of poor damage tolerance associated with advanced composite materials. In this study, the unidirectional laminate strengths and moduli, notched (open-hole) and unnotched tension and compression properties of quasi-isotropic laminates, and compression-after-impact strengths of five carbon fiber/toughened matrix composites, IM7/E7T1-2, IM7/X1845, G40-800X/5255-3, IM7/5255-3, and IM7/5260, have been evaluated. The compression-after-impact (CAI) strengths were determined primarily by impacting quasi-isotropic laminates with the NASA Langley air gun. A few CAI tests were also made with a drop-weight impactor. For a given impact energy, compression-after-impact strengths were determined to be dependent on impactor velocity. Properties and strengths for the five materials tested are compared with NASA data on other toughened matrix materials (IM7/8551-7, IM6/1808I, IM7/977-2, IM7/F655, and T800/F3900). This investigation found that all five materials were stronger and more impact damage tolerant than more brittle carbon/epoxy composite materials currently used in aircraft structures.

Introduction

The use of carbon fiber/epoxy composite materials in primary aircraft applications has been limited by poor damage tolerance. The strength of these materials is greatly reduced by impact damage as well as by fastener holes. Carbon/epoxy composites used for primary structures must be damage tolerant and resist delamination. The use of toughened matrix composites (thermoset/thermoplastic blends) offers a potentially attractive solution to the problem by providing the mechanical properties of a thermoset with the toughness of a thermoplastic.

Many toughened epoxy and bismaleimide resin materials (table 1) are now commercially available, and several of these materials (IM7/977-2, IM7/F655, T800/F3900, IM7/8551-7, and IM6/1808I) have been previously evaluated at the NASA Langley Research Center (refs. 1 and 2). These toughened materials have substantially better strength properties than earlier brittle carbon/epoxy composites such as Thornel T-300/Narmco 5208. (Thornel is a trademark of Union Carbide Corporation and Narmco is a trademark of Narmco Materials.) This study continued the evaluation of toughened matrix composites. Properties are presented for five new commercially available toughened materials, IM7/E7T1-2, IM7/X1845, G40-800X/5255-3, IM7/5255-3, and IM7/5260, which offer the potential for similar improvements in structural performance.

The results of an experimental evaluation of these five new materials are presented. The data include unidirectional laminate strengths and moduli, notched (open-hole) and unnotched tension and compression properties of quasi-isotropic laminates, and compression-after-impact strengths. These data are compared with the properties of the five carbon/toughened matrix materials previously tested at Langley (refs. 1 and 2). All work reported was performed at the Langley Research Center.

Materials

The IM7/E7T1-2 material was supplied by U.S. Polymeric. The E7T1-2 material is a two-phase toughened epoxy resin, and the Hercules IM7 carbon fiber has a high failure strain (1.6 percent). The IM7/X1845 material was obtained from American Cyanamid Company and utilizes an engineered two-phase epoxy resin. The G40-800X/5255-3, IM7/5255-3, and IM7/5260 materials were supplied by BASF. The Celion G40-800X is a high-strength carbon fiber manufactured by BASF. The 5255-3 is a two-phase toughened epoxy resin, and the 5260 is a modified bismaleimide (BMI). High-temperature capabilities are provided by BMI resins, but they generally have lower failure strains than epoxy resins. Table 1 presents the approximate cost of these materials and the five materials previously tested at Langley (refs. 1 and 2). These 10 new materials are two to six times more expensive than the Hercules AS4/3501-6 material, an older brittle epoxy composite.

Manufacturer-supplied information on the prepreg materials is provided in table 2. Laminates were

fabricated from 12-in-tape prepreg materials by using the manufacturer's recommended cure cycles (figs. 1 to 4) and standard bagging procedures described in reference 3. After fabrication, the laminates were ultrasonically inspected and determined to be of good quality. The fiber volume fractions were determined by acid digestion, ASTM D 3171-76 (ref. 4).

Test Specimens

Unidirectional (0° and 90°), cross-plied $(+45°/-45°)_{2s}$, and quasi-isotropic $(45°/0°/-45°/90°)_{ns}$ laminates were machined into test specimens for the test matrix shown in table 3. The specimen configurations (fig. 5) were similar to those recommended in references 3 and 5 except for the short-block compression (SBC) specimen (fig. 5(b)), which is a Langley configuration. Strain gauges were applied to the specimens as recommended in references 3 and 5, and several specimens of each type were tested to obtain average mechanical properties.

Test Procedures

Environmental Conditioning

Most specimens were tested at room temperature (see table 3) and had a moisture content resulting from normal laboratory exposure. This condition is referred to as "room temperature, dry" (RTD). Other specimens were soaked in a 160°F water bath for 45 days and then tested at 180°F. This condition is referred to as "hot, wet" (HW). The hot, wet specimens were soaked after being impacted or drilled. The moisture absorption was determined by weighing selected open-hole compression specimens in the RTD condition before soaking and again after soaking for 45 days. The data showed that the IM7/E7T1-2 and IM7/X1845 materials had a moisture absorption of 0.40 percent and 0.52 percent, respectively. As expected, the G40-800X/5255-3 and IM7/5255-3 materials had similar moisture absorption of 0.37 percent and 0.41 percent, respectively; however, the IM7/5260 material, a bismaleimide, absorbed the most moisture with an absorption of 0.69 percent. All the hot, wet specimens were strain gauged immediately upon removal from the water and were tested within 1 to 2 hours.

Ply-Level Tension and Compression Tests

All tension specimens (fig. 5(a)) were tested in a 55-kip electronic servo-hydraulic testing machine with hydraulic-pressure-actuated grips at a displacement rate of 0.05 in/min. The 0° tension specimens were tabbed with fiberglass. The 90° and 45°/−45° tension specimens however were not tabbed; instead, they were gripped with 180-grit fabric and Lexan film to eliminate grip damage to the specimens. The grit fabric was placed in direct contact with the specimen being tested, whereas the Lexan film was placed in direct contact with the testing machine grips. The 0° compression specimens were tested in a short-block compression configuration, shown in figure 5(b). The 0° compression specimens were installed in an SBC fixture (fig. 6(a)), which clamps the specimen ends to avoid "brooming" failures. Compression specimens were tested in a 120-kip hydraulic testing machine at a displacement rate of 0.05 in/min. During both tension and compression testing, the stress and strain data were recorded throughout the tests with an IBM PC data acquisition system.

Unnotched and Notched (Open-Hole) Tension and Compression Tests

Data were obtained from quasi-isotropic unnotched and notched (open-hole) tension and compression specimens, figures 5(c), 5(d), and 5(e). Unnotched compression tests were performed with the SBC test fixture shown in figure 6(a). Notched compression specimens were tested in a compression fixture (fig. 6(b)), which not only clamps the ends but also provides knife-edge side supports to prevent global buckling. All compression tests were made in a 120-kip hydraulic testing machine at a displacement rate of 0.05 in/min. The tension specimens were tested in a 55-kip electronic servo-hydraulic testing machine with hydraulic-pressure-actuated grips. In the same manner as the ply-level tension specimens, 180-grit fabric and General Electric Lexan film were used in the grips to prevent grip damage to the specimen, and a displacement rate of 0.05 in/min was used.

Compression-After-Impact Tests

Compression-after-impact tests, in most cases, were performed on specimens (fig. 5(f)) impacted by a 0.5-in-diameter aluminum ball fired from an air gun while supported in the loading fixture (fig. 6(b)). The air-gun impact apparatus (fig. 7), a Langley development, is described in references 1 and 2. The velocity of the aluminum projectile is controlled to produce a desired impact energy. In this work, specimens were impacted at energies per unit thickness of 1000 and 1500 in-lb/in. A few specimens were impacted with a 10-lb, 0.5-in. hemispherical steel-tip drop-weight impactor by using the technique described in reference 5. After impact, all specimens were ultrasonically inspected to determine the damage area and then instrumented with strain gauges. The specimens were loaded in a compression fixture (fig. 6(b)),

which clamps the ends to prevent brooming failures and provides knife-edge support to the sides to prevent global buckling. During testing, a displacement rate of 0.05 in/min was maintained while the load and strain data were recorded on an IBM PC data acquisition system.

Results and Discussion

Typical stress-strain plots for the five materials evaluated are shown in figures 8 to 12. The mechanical properties data for all individual specimens are presented in tables 4 to 14 and the average properties are compared in figures 13 to 21. For comparison purposes, these figures include data for five previously tested toughened resin systems, IM7/8551-7 and IM6/1808I from reference 1 and IM7/977-2, IM7/F655, and T800/F3900 from reference 2. The IM7/977-2 material combines high-failure-strain carbon fibers with a two-phase toughened epoxy. The IM7/F655 material uses a two-phase toughened bismaleimide resin. The IM7/8551-7, IM6/1808I, and T800/F3900 materials are all high-failure-strain carbon fiber/toughened epoxy systems. The 1808I resin system incorporates a 1-mil thermoplastic film applied to one side of the prepreg tape, whereas the 8551-7 and F3900 resins combine a toughened epoxy with small elastomeric particles that form a compliant interleaf between fiber plies. Because these particles are larger than the space between fibers, they are mostly confined to the interply region.

Ply-Level Properties (0°, 90°, and ±45° Laminates)

Table 4 presents the results of the 0° tension tests for the IM7/E7T1-2, IM7/X1845, G40-800X/5255-3, IM7/5255-3, and IM7/5260 materials. In table 4 and subsequent tables, modulus values are given in million pounds per square inch (Msi). Unidirectional tension tests are primarily a measure of fiber strength; therefore, similar strengths were expected for the four materials made with IM7 fibers. However, the four materials composed of IM7 fibers produced tension strengths that ranged from 328.95 ksi for the IM7/E7T1-2 material to 411.23 ksi for the IM7/5260 material, with nominal fiber volume fractions of 56.8 percent and 60.5 percent, respectively. The 0° tension strength and modulus values are shown in figure 13. Although all 10 toughened materials had essentially the same modulus, the strengths varied widely with the IM6/1808I material being the lowest and the IM7/5260 the highest. Overall, the five new materials exhibited the same tension strengths as the five previously tested toughened systems.

The unidirectional compression data for four of the five materials tested in this work are presented in table 5. Because of a lack of sufficient material, unidirectional compression tests were not performed on the IM7/5255-3 material. Unidirectional compression testing was performed to obtain values of modulus and Poisson's ratio. Meaningful values of unidirectional compression strengths however cannot be obtained from the short-block configuration used in this study. In the SBC configuration, failure of the unidirectional specimens occurs because of longitudinal splitting of the specimens. Therefore, the compression strengths given in table 5 are not a true indication of the material's unidirectional compression strength. The modulus and Poisson's ratio are measured below the stress at which splitting occurs; therefore, they are valid indicators of the material's properties. The unidirectional compression and tensile modulus values are compared in figure 14 and show similar results, although the tensile modulus values are slightly higher than the compression values. Like moduli, the Poisson's ratio for the five new materials are virtually identical. Both unidirectional compression and tension properties of the new materials are similar to those of the other toughened matrix materials.

The 90° tension test is a measure of resin properties and the data obtained are presented in table 6. The results are compared with other toughened matrix systems in figure 15. The five new materials had tension moduli that ranged from 1.79 Msi for the G40-800X/5255-3 to 1.42 Msi for the IM7/E7T1-2 and each had higher modulus values than the five previous matrix systems. The IM7/E7T1-2, IM7/X1845, IM7/977-2, IM7/F3900, and IM7/8551-7 materials had similar tensile strengths of about 10 ksi, whereas the G40-800X/5255-3 and IM7/5255-3 materials had values near 8 ksi. The tension strength of the IM7/5260 material was superior to that of the other materials, which was a surprising result; this material was expected to have a strength similar to the IM7/F655 material, also a BMI.

The ±45° test results, which depend on both the resin matrix and the fiber/matrix interface, are presented in table 7. Figure 16 shows the average extensional moduli and strengths of the five materials along with the average values of the five previously tested materials. The shear moduli (G_{12}) for the five new toughened matrix materials were determined from the ±45° tension test, ASTM D 3518-76 (ref. 6). The five new materials had similar strengths and they performed as well as or better than the five previously tested materials. The materials tested

in this work had higher modulus values than those measured for the other toughened systems. Shear failure strengths were not obtained from this test because of the nonlinear stress-strain response of the samples at high loads when the fibers are not oriented at ±45°

Notched (Open-Hole) and Unnotched Properties of Quasi-Isotropic Laminates

The notched (open-hole) and unnotched tension strengths for the five materials are presented in tables 8 and 9 and compared with the previously tested materials in figure 17. (Notched strengths are based on gross specimen cross-sectional area.) The IM7/E7T1-2 and IM7/X1845 materials show similar notched and unnotched tension strengths, whereas the IM7/5255-3 and IM7/5260 materials had slightly higher ultimate strengths. The G40-800X/5255-3 material outperformed all the other materials in both notched tension and unnotched tension. Because IM7 and G40-800X fibers have similar modulus values (about 40 Msi), the greater strengths shown by the G40-800X fiber may be due to greater fiber/matrix adhesion. The nine materials made with 40-Msi fibers performed better in these tests than did the IM6/1808I material, which incorporates a lower modulus fiber. As shown in figure 17, notches (0.25-in. diameter) significantly reduced the tension strengths of all the materials, but increasing the hole size to a 0.5-in. diameter did not markedly alter the reduction. A measure of merit in notched RTD tension tests is for specimens with 0.25-in-diameter holes to attain a failure stress of 60 ksi. Except for the IM6/1808I material, all the toughened matrix materials met the goal of 60 ksi.

The notched (open-hole) and unnotched compression strengths of the five materials are shown in tables 10 and 11 and compared in figure 18. The unnotched data were obtained with the SBC configuration. The IM7/E7T1-2, G40-800X/5255-3, and IM7/5255-3 materials showed similar unnotched compression strengths (97.1, 99.9, and 95.1 ksi), and these strengths were in the same range (90–100 ksi) as the previously tested materials. The IM7/X1845 material showed the poorest unnotched strength (84.5 ksi), whereas the IM7/5260 material had the highest ultimate strength (117.9 ksi). As shown in figure 18, open holes significantly reduce the compression strength of all the materials (open-hole strengths are based on gross specimen cross-sectional area), and as hole diameter increased, open-hole compression (OHC) strengths decreased. Again, the IM7/5260 material showed the highest OHC strengths and the IM7/X1845 material showed the lowest OHC strengths. A measure of merit in notched RTD compression tests is for specimens with a 0.25-in-diameter hole to attain a failure stress of 42 ksi. All the toughened matrix materials met this goal of 42 ksi.

The compression properties for the HW notched laminates are shown in table 12 and compared in figure 19. The hot, wet conditioning resulted in reduced OHC strengths for all the materials. The BMI materials, IM7/5260 and IM7/F655, were expected to have good high-temperature properties. Their reductions in strength were 12.9 and 15.0 percent, respectively. However, the IM7/5255-3 material was the least affected by the HW conditions, as evidenced by a strength reduction of only 6.7 percent. As shown in figure 19, the G40-800X/5255-3, IM7/5255-3, IM7/5260, and IM7/F655 materials met the goal of 42 ksi, even when subjected to HW conditioning.

Compression-After-Impact Results

The average compression-after-impact (CAI) strengths measured in this investigation are listed in table 13. Figure 20 shows a comparison of these strengths and previous data from references 1 and 2. The results in figure 20 show that drop-weight CAI strengths are consistently higher than air-gun CAI strengths for the same impact energy. Because of a lack of sufficient material, drop-weight testing was not performed on the IM7/5255-3 material. Specimens subjected to a 1500 in-lb/in. drop-weight impact also had higher CAI strengths than when subjected to a lower impact energy per unit thickness of 1000 in-lb/in. with the air gun. The only exception was the T800/F3900 material. The three toughened epoxy materials of this investigation subjected to the drop-weight tests had similar drop-weight CAI strengths. All four toughened epoxy materials had similar air-gun CAI strengths (values are within 10 percent for each impact energy level). The IM7/5260 material, a BMI, had the lowest air-gun CAI strengths of the five materials tested, but its drop-weight CAI strength was similar to the epoxy matrix laminates. These results indicate that impact velocity is an important factor in determining damage tolerance; this factor is discussed in more detail subsequently. The T800/F3900, IM7/8551-7, and IM6/1808I materials, which incorporate a compliant interleaf layer for added toughness, had the highest CAI strengths of all 10 materials tested in the Langley program. As shown in table 14 and figure 21, hot, wet conditioning reduced the CAI strengths of

the materials studied in this work (reductions ranged from 5.0 to 16.1 percent).

The damage areas (determined from C-scans) of the materials studied in this work are plotted versus their corresponding CAI strengths in figures 22 and 23. Data from references 1 and 2 are also included. In figure 22, CAI strengths are plotted for air-gun impacts at 1000 and 1500 in-lb/in. For air-gun impacts, the three interleaved materials (T800/F3900, IM7/8551-7, and IM6/1808I depicted by dashed lines) had smaller damage areas and higher CAI strengths than the other toughened systems. Figure 23 presents the results obtained for the drop-weight impact tests. All the materials except IM7/F655 have similar CAI strengths of about 40 ksi, which is substantially greater than most air-gun values. As shown in figures 22 and 23, the drop-weight impact procedure produced less damage area and resulted in higher CAI strengths than the air-gun impact procedure for the same impact energy to thickness ratio (1500 in-lb/in.) for all the materials subjected to both test procedures.

An explanation for the difference in CAI strengths obtained by drop-weight and air-gun impacts is given in references 7 and 8. A composite laminate struck by a fast-moving projectile (air-gun impactor, 540 ft/sec) undergoes a localized deformation for a brief time. A state of transverse shear stress is caused by this local deformation, which in turn causes delaminations if it exceeds the interlaminar shear strength of the composite. On the other hand, the drop-weight impact is a much slower impact (14 ft/sec) for the same energy level. Because of the slower impact, global deformations occur; thus, the transverse shear stresses are reduced.

Summary Strength Comparisons

The undamaged mechanical properties of the five materials evaluated in this work are comparable with the properties for the five previously evaluated materials (refs. 1 and 2); therefore, these five materials also offer improved damage tolerance and mechanical properties when compared with earlier, more brittle composite materials. Figures 24 and 25 compare the strength performance of the 10 composite materials tested in this evaluation project.

Laminate tension strength (open-hole specimen) versus tension modulus for quasi-isotopic laminates is shown in figure 24. The results shown are those from specimens with a 0.25-in-diameter open hole. In this comparison, the G40-800X/5255-3 laminates provided the best combination of tension properties.

Figure 25 shows the open-hole (0.25-in-diameter) compression strength versus the compression-after-impact (CAI) strength for quasi-isotropic laminates made with the 10 materials. Data shown are from air-gun impact tests at an energy level to laminate thickness ratio of 1500 in-lb/in. In this comparison, superior CAI strengths were demonstrated by the two composite materials having a compliant interleaf between plies. From a design standpoint, it is desirable for the CAI strength of a laminate to be greater than its open-hole compression strength. None of the materials demonstrated this combination of properties.

Conclusions

Unidirectional laminate strengths and moduli, notched (open-hole) and unnotched tension and compression properties of quasi-isotropic laminates, and compression-after-impact strengths of five carbon fiber/toughened matrix composites (IM7/E7T1-2, IM7/X1845, G40-800X/5255-3, IM7/5255-3, and IM7/5260) were determined in this investigation. The results of this work lead to the following conclusions:

1. These five toughened composites offer improved damage tolerance and mechanical properties when compared with earlier, more brittle composite materials presently used in aircraft structures.

2. The undamaged mechanical properties of the five materials evaluated in this work are comparable with the properties for previously evaluated toughened resin systems, but their damage tolerance is not as good as materials that incorporate a compliant interleaf (T800/F3900, IM7/8551-7, and IM6/1808I) for added toughness.

3. Compression-after-impact strengths are dependent on impactor velocity for a given impact energy.

4. A combination of heat and moisture degraded the compression strength of all the notched and impacted materials evaluated in this investigation.

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References

1. Dow, Marvin B.; and Smith, Donald L.: *Properties of Two Composite Materials Made of Toughened Epoxy Resin and High-Strain Graphite Fiber.* NASA TP-2826, 1988.

2. Smith, Donald L.; and Dow, Marvin B.: *Properties of Three Graphite/Toughened Resin Composites.* NASA TP-3102, 1991.

3. ACEE Composites Project Office, compiler: *NASA/ Aircraft Industry Standard Specification for Graphite Fiber/Toughened Thermoset Resin Composite Material.* NASA RP-1142, 1985.

4. Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion. ASTM Designation: D 3171-76 (Reapproved 1990), Volume 15.03 of *1990 Annual Book of ASTM Standards*, c.1990, pp. 123–125.

5. ACEE Composites Project Office, compiler: *Standard Tests for Toughened Resin Composites—Revised Edition.* NASA RP-1092, 1983.

6. Standard Practice for Inplane Shear Stress-Strain Response of Unidirectional Reinforced Plastics. ASTM Designation: D 3518-76 (Reapproved 1982), Volume 15.03 of *1990 Annual Book of ASTM Standards*, c.1990, pp. 145–148.

7. Williams, Jerry G.; and Rhodes, Marvin D.: *The Effect of Resin on the Impact Damage Tolerance of Graphite-Epoxy Laminates.* NASA TM-83213, 1981.

8. Williams, Jerry G.; O'Brien, T. Kevin; and Chapman, A. J., III: Comparison of Toughened Composite Laminates Using NASA Standard Damage Tolerance Tests. *ACEE Composite Structures Technology—Review of Selected NASA Research on Composite Materials and Structures*, NASA CP-2321, 1984, pp. 51–73.

Table 1. Materials Evaluated

Supplier	Fiber/matrix	Matrix resin[a]	Approximate cost per lb[b]
Present materials:			
U.S. Polymeric	IM7/E7T1-2	TPT epoxy	95
American Cyanamid Co.	IM7/X1845	TPT epoxy	300
BASF	G40-800X/5255-3	TPT epoxy	200
BASF	IM7/5255-3	TPT epoxy	200
BASF	IM7/5260	TPT BMI	200
Reference materials:			
Fiberite Corp.	IM7/977-2	TPT epoxy	92
Hexcel Corp.	IM7/F655	TPT BMI	106
Hexcel Corp.	T800/F3900	TEP epoxy	94
Hercules Inc.	IM7/8551-7	TEP epoxy	132
American Cyanamid Co.	IM6/1808I	TTF epoxy	135

[a]TPT = Two-phase toughened.
TEP = Toughened with elastomeric particles.
TTF = Toughened with a 1-mil thermoplastic film.
[b]For reference, Hercules AS4/3501-6 costs about $45/lb.

Table 2. Composite Prepreg Information

Material	Fiber	Fiber areal wt, g/m^2	Cure temp., °C	Volatile content, percent	Wet resin content, wt, percent	Lot no.
IM7/E7T1-2	Hercules IM7	146	154	1.35	37	2W6874
IM7/X1845	Hercules IM7	145	177	<0.50	36	LX10452-104
G40-800X/5255-3	Celion G40-800X	145	177	<0.50	35	N/A
IM7/5255-3	Hercules IM7	145	177	<0.05	35	18058-00
IM7/5260	Hercules IM7	145	190	<1.00	35	18896-00

Table 3. Test Matrix

Laminate ply orientation	Loading direction	Test condition (a)	Quantity	Specimen configurations, see figure—
$(0)_8$	0° Tension	RTD, unnotched	5	5(a)
$(0)_8$	90° Tension	RTD, unnotched	5	5(a)
$(0)_{24}$	0° Compression	RTD, unnotched	5	5(b)
$(45/-45)_{2s}$	±45 Shear	RTD, unnotched	5	5(b)
$(45/0/-45/90)_{2s}$	Tension	RTD, unnotched	5	5(c)
$(45/0/-45/90)_{2s}$	Tension	RTD, 1/2-in. hole	3	5(d)
$(45/0/-45/90)_{2s}$	Tension	RTD, 1/4-in. hole	3	5(d)
$(45/0/-45/90)_{5s}$	Compression	RTD, unnotched	5	5(b)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1/4-in. hole	3	5(e)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1/2-in. hole	3	5(e)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1-in. hole	3	5(e)
$(45/0/-45/90)_{5s}$	Compression	HW, 1/4-in. hole	3	5(e)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1000 in-lb/in., AG	3	5(f)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1500 in-lb/in., AG	3	5(f)
$(45/0/-45/90)_{5s}$	Compression	HW, 1000 in-lb/in., AG	3	5(f)
$(45/0/-45/90)_{5s}$	Compression	HW, 1500 in-lb/in., AG	3	5(f)
$(45/0/-45/90)_{5s}$	Compression	RTD, 1500 in-lb/in., DW	1	5(f)

[a]RTD = Room temperature, ambient moisture content.
HW = 180°F, hot, wet.
AG = Air-gun impact.
DW = Drop-weight impact.

Table 4. Unnotched RTD Tension Properties for 0° Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 55.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BP-0T1	10.00	1.003	0.050	15.84	315.92	2.70	18.98	0.36
BP-0T2	10.00	1.004	0.050	17.16	341.86	1.54	20.60	0.34
BP-0T3	10.00	1.004	0.050	17.12	341.04	0.95	20.50	0.34
BP-0T4	10.00	1.003	0.050	15.78	314.72	0.75	20.93	0.34
BP-0T5	10.00	1.004	0.049	16.29	331.19	2.74	20.65	0.34
Average		1.004	0.050	16.44	328.95	1.74	20.33	0.34
Standard deviation		0.000	0.000	0.60	11.75	0.84	0.69	0.01

[a]At 0.2-percent strain.

(b) IM7/1845 laminate; nominal fiber volume fraction, 60.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
AMC-0T1	10.00	1.002	0.049	17.25	350.08	1.49	20.82	0.33
AMC-0T2	10.00	1.002	0.047	17.57	374.13	1.50	22.50	0.34
AMC-0T3	10.00	1.001	0.048	16.20	338.61	1.37	21.53	0.35
AMC-0T4	10.00	1.002	0.048	17.17	358.59	1.45	21.80	0.33
AMC-0T5	10.00	1.002	0.048	15.92	333.89	1.35	21.99	0.35
Average		1.002	0.048	16.82	351.06	1.43	21.73	0.34
Standard deviation		0.000	0.001	0.64	14.42	0.06	0.55	0.01

[a]At 0.2-percent strain.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 62.0 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BASF-0T1	10.00	1.005	0.045	19.21	426.68	1.68	22.74	0.33
BASF-0T2	10.00	1.005	0.044	16.88	382.50	1.56	22.42	0.36
BASF-0T3	10.00	1.008	0.045	17.80	395.98	1.54	22.62	0.34
BASF-0T4	10.00	1.006	0.046	16.29	355.05	1.43	22.08	0.32
BASF-0T5	10.00	1.008	0.044	16.85	380.67	1.53	22.24	0.31
Average		1.006	0.045	17.40	388.18	1.55	22.42	0.33
Standard deviation		0.001	0.001	1.03	23.36	0.08	0.24	0.02

[a]At 0.2-percent strain.

Table 4. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 63.3 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5255-0T1	10.00	1.000	0.044	17.55	395.11	1.58	22.06	0.35
5255-0T2	10.00	1.002	0.045	17.23	384.58	1.56	21.66	0.33
5255-0T3	10.00	1.002	0.045	17.05	380.67	1.66	21.55	0.34
5255-0T4	10.00	1.001	0.046	18.28	401.21	1.65	21.00	0.32
5255-0T5	10.00	1.002	0.047	17.55	375.05	1.66	21.10	0.33
Average		1.002	0.045	17.53	387.32	1.62	21.47	0.33
Standard deviation		0.001	0.001	0.42	9.55	0.04	0.39	0.01

[a]At 0.2-percent strain.

(e) IM7/5260 laminate; nominal fiber volume fraction, 58.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5260-0T1	10.00	1.006	0.046	18.72	404.55		21.43	0.33
5260-0T2	10.00	1.006	0.045	18.74	413.92		21.20	0.32
5260-0T3	10.00	1.006	0.045	19.37	427.97	1.70	22.20	0.33
5260-0T4	10.00	1.006	0.045	19.14	422.83	1.72	21.66	0.33
5260-0T5	10.00	1.006	0.046	17.90	386.89	1.69	20.79	0.34
Average		1.006	0.045	18.78	411.23	1.70	21.46	0.33
Standard deviation		0.000	0.000	0.50	14.55	0.01	0.47	0.01

[a]At 0.2-percent strain.

Table 5. Unnotched RTD Compression Properties for 0° Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 55.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BP-0C1	1.75	1.500	0.130	26.58	136.30	0.75	19.40	0.33
BP-0C2	1.75	1.500	0.130	25.80	132.30	0.72	19.80	0.30
BP-0C3	1.75	1.500	0.130	26.48	135.80	0.74	19.50	0.31
BP-0C4	1.75	1.500	0.130	24.53	125.80	0.67	20.30	0.30
BP-0C5	1.75	1.500	0.130	25.90	132.80	0.71	19.80	0.31
Average		1.500	0.130	25.86	132.60	0.74	19.76	0.31
Standard deviation		0.000	0.000	0.73	3.75	0.02	0.31	0.01

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 60.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
AMC-0C1	1.75	1.501	0.123	22.30	120.76	0.62	19.97	0.35
AMC-0C2	1.75	1.501	0.125	23.24	123.86	0.64	20.32	0.33
AMC-0C3	1.75	1.501	0.122	24.88	135.89	0.70	20.37	0.34
AMC-0C4	1.75	1.502	0.122	23.54	128.44	0.66	20.49	0.34
AMC-0C5	1.75	1.502	0.122	22.93	125.14	0.64	20.29	0.34
Average		1.501	0.123	23.38	126.82	0.65	20.29	0.34
Standard deviation		0.000	0.001	0.86	5.16	0.03	0.17	0.01

[a]At 0.2-percent strain.

Table 5. Concluded

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 62.0 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BASF-0C1	1.75	1.501	0.127	22.49	117.99	0.64	20.71	0.32
BASF-0C2	1.75	1.501	0.129	24.52	126.64	0.64	20.25	0.33
BASF-0C3	1.75	1.501	0.128	22.95	119.43	0.65	15.72	0.27
BASF-0C4	1.75	1.500	0.127	24.03	126.13	0.64	20.63	0.33
BASF-0C5	1.75	1.501	0.130	21.48	110.09	0.55	20.61	0.32
Average		1.501	0.128	23.09	120.06	0.62	19.58	0.31
Standard deviation		0.000	0.001	1.09	6.07	0.04	1.94	0.02

[a]At 0.2-percent strain.

(d) IM7/5260 laminate; nominal fiber volume fraction, 58.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5260-0C1	1.75	1.506	0.129	27.30	140.53	0.73	20.18	0.36
5260-0C2	1.75	1.506	0.130	27.15	138.70	0.71	20.24	0.37
5260-0C3	1.75	1.507	0.130	25.49	130.12	0.67	20.20	0.36
5260-0C4	1.75	1.507	0.129	25.55	131.43	0.66	20.68	0.35
5260-0C5	1.75	1.506	0.130	25.87	132.15	0.71	19.59	0.37
Average		1.506	0.130	26.27	134.59	0.70	20.18	0.36
Standard deviation		0.000	0.000	0.79	4.20	0.03	0.35	0.01

[a]At 0.2-percent strain.

Table 6. Unnotched RTD Tension Properties for 90° Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 56.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BP1-9T2	10.00	1.004	0.050	0.52	10.35	0.83	1.33	0.02
BP1-9T3	10.00	1.005	0.048	0.47	9.82	0.74	1.47	0.01
BP1-9T4	10.00	1.004	0.049	0.49	9.97	0.79	1.46	0.02
BP1-9T5	10.00	1.003	0.048	0.49	10.15	0.79	1.42	0.02
Average		1.004	0.049	0.49	10.07	0.79	1.42	0.02
Standard deviation		0.001	0.001	0.02	0.20	0.03	0.06	0.00

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 58.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
AMC-9T1	10.00	1.002	0.047	0.51	10.84	0.90	1.66	0.02
AMC-9T2	10.00	1.001	0.047	0.43	9.20	0.75	1.47	0.02
AMC-9T3	10.00	1.001	0.045	0.48	10.66	0.86	1.57	0.01
AMC-9T4	10.00	1.001	0.046	0.45	9.78	0.78	1.60	0.01
AMC-9T5	10.00	1.002	0.045	0.42	9.30	0.72	1.47	0.01
Average		1.001	0.046	0.46	9.96	0.80	1.55	0.01
Standard deviation		0.000	0.001	0.03	0.68	0.07	0.07	0.00

[a]At 0.2-percent strain.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 64.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BASF-9T1	10.00	1.002	0.043	0.31	7.09	0.49	1.60	0.01
BASF-9T2	10.00	1.002	0.043	0.35	8.08	0.57	1.56	0.01
BASF-9T3	10.00	1.001	0.042	0.34	8.01	0.57	1.58	0.02
BASF-9T4	10.00	1.001	0.042	0.27	6.41	0.37	2.11	0.01
BASF-9T5	10.00	1.001	0.042	0.27	6.42	0.36	2.10	0.02
Average		1.001	0.042	0.31	7.20	0.47	1.79	0.01
Standard deviation		0.000	0.000	0.03	0.73	0.09	0.26	0.00

[a]At 0.2-percent strain.

Table 6. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 63.3 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5255-9T1	10.00	1.002	0.045	0.38	8.50	0.61	1.63	0.02
5255-9T2	10.00	1.001	0.044	0.39	8.91	0.66	1.60	0.01
5255-9T3	10.00	1.001	0.043	0.34	7.83	0.53	1.69	0.02
5255-9T4	10.00	1.001	0.042	0.33	7.71	0.52	1.73	0.01
5255-9T5	10.00	1.002	0.042	0.35	8.38	0.57	1.66	0.01
Average		1.001	0.043	0.36	8.27	0.58	1.66	0.01
Standard deviation		0.000	0.001	0.02	0.44	0.05	0.05	0.00

[a]At 0.2-percent strain.

(e) IM7/5260 laminate; nominal fiber volume fraction, 60.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5260-9T1	10.00	1.006	0.047	0.59	12.56	0.94	1.43	0.02
5260-9T2	10.00	1.006	0.047	0.60	12.66	0.92	1.55	0.02
5260-9T3	10.00	1.006	0.046	0.54	11.67	0.87	1.45	0.02
5260-9T4	10.00	1.006	0.046	0.55	11.97	0.86	1.48	0.02
5260-9T5	10.00	1.006	0.046	0.60	12.91	0.95	1.47	0.02
Average		1.006	0.046	0.58	12.35	0.91	1.48	0.02
Standard deviation		0.000	0.000	0.02	0.46	0.04	0.04	0.00

[a]At 0.2-percent strain.

Table 7. Unnotched RTD Tension Properties for ±45° Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 55.7 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Shear modulus,[b] ksi	Modulus,[a] Msi	Poisson's ratio[a]
BP1-ST1	10.00	1.003	0.050	2.00	39.79	3.85	760.90	2.63	0.73
BP1-ST2	10.00	1.003	0.050	2.00	39.88	3.86	746.30	2.65	0.73
BP1-ST3	10.00	1.004	0.049	2.03	41.27	3.86	750.20	2.60	0.73
BP1-ST4	10.00	1.004	0.048	2.03	41.96	3.86	796.20	2.70	0.73
BP1-ST5	10.00	1.004	0.049	2.03	41.08		787.80	2.70	0.72
Average		1.004	0.049	2.02	40.79	3.86	768.28	2.66	0.73
Standard deviation		0.000	0.001	0.01	0.84	0.00	20.12	0.04	0.00

[a]At 0.2-percent strain.
[b]In-plane shear modulus calculated for a 0° laminate.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 60.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Shear modulus,[b] ksi	Modulus,[a] Msi	Poisson's ratio[a]
AMC-ST1	10.00	1.001	0.045	1.74	38.64	3.83	687.40	2.50	0.82
AMC-ST2	10.00	1.001	0.046	1.75	38.04	3.83	707.80	2.57	0.82
AMC-ST3	10.00	1.002	0.046	1.75	38.04	3.82	696.30	2.45	0.81
AMC-ST4	10.00	1.001	0.047	1.75	37.14	3.83	665.80	2.45	0.80
AMC-ST5	10.00	1.001	0.047	1.66	35.32	3.83	678.80	2.50	0.80
Average		1.001	0.046	1.73	37.44	3.83	687.22	2.49	0.81
Standard deviation		0.000	0.001	0.03	1.16	0.00	14.39	0.04	0.01

[a]At 0.2-percent strain.
[b]In-plane shear modulus calculated for a 0° laminate.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 61.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Shear modulus,[b] ksi	Modulus,[a] Msi	Poisson's ratio[a]
BASF-ST1	10.00	1.002	0.043	1.75	40.39	3.78	869.00	3.14	0.77
BASF-ST2	10.00	1.001	0.044	1.76	40.30	3.79	837.31	2.99	0.79
BASF-ST3	10.00	1.002	0.043	1.70	39.71	3.79	866.36	3.08	0.77
BASF-ST4	10.00	1.002	0.044	1.67	37.69	3.78	801.93	2.84	0.77
BASF-ST5	10.00	1.002	0.043	1.64	38.46	3.79	848.93	3.01	0.78
Average		1.002	0.043	1.70	39.31	3.79	844.71	3.01	0.78
Standard deviation		0.000	0.001	0.05	1.06	0.00	24.34	0.10	0.01

[a]At 0.2-percent strain.
[b]In-plane shear modulus calculated for a 0° laminate.

Table 7. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 63.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Shear modulus,[b] ksi	Modulus,[a] Msi	Poisson's ratio[a]
5255-ST1	10.00	1.001	0.045	1.58	34.92	3.83	999.40	3.75	0.75
5255-ST2	10.00	1.003	0.044	1.67	37.61	3.83	781.10	2.75	0.76
5255-ST3	10.00	1.002	0.044	1.65	37.35	3.82	804.20	2.84	0.77
5255-ST4	10.00	1.002	0.044	1.71	39.00	3.83	803.40	2.86	0.77
5255-ST5	10.00	1.002	0.044	1.69	38.03	3.82	781.70	2.85	0.76
Average		1.002	0.044	1.66	37.38	3.83	833.96	3.01	0.76
Standard deviation		0.001	0.000	0.05	1.35	0.00	83.32	0.37	0.01

[a]At 0.2-percent strain.
[b]In-plane shear modulus calculated for a 0° laminate.

(e) IM7/5260 laminate; nominal fiber volume fraction, 58.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Shear modulus,[b] ksi	Modulus,[a] Msi	Poisson's ratio[a]
5260-ST1	10.00	1.004	0.046	1.72	37.21	3.79	893.70	3.08	0.72
5260-ST2	10.00	1.005	0.046	1.77	38.28	3.79	881.04	3.06	0.74
5260-ST3	10.00	1.005	0.045	1.77	39.16	3.78	907.80	3.14	0.73
5260-ST4	10.00	1.005	0.045	1.74	38.47	3.79	947.70	3.27	0.73
5260-ST5	10.00	1.005	0.046	1.65	35.76	3.79	904.30	3.13	0.73
Average		1.005	0.046	1.73	37.78	3.79	906.91	3.14	0.73
Standard deviation		0.000	0.000	0.04	1.19	0.00	22.43	0.07	0.01

[a]At 0.2-percent strain.
[b]In-plane shear modulus calculated for a 0° laminate.

Table 8. Unnotched RTD Tension Properties for Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 54.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BP4-QT1	10.00	1.005	0.095	12.85	134.61	1.67	7.91	0.29
BP4-QT2	10.00	1.002	0.096	13.36	138.89	1.75	7.88	0.29
BP4-QT3	10.00	1.003	0.097	12.42	127.65	1.60	7.96	0.29
BP4-QT4	10.00	1.003	0.095	12.46	130.79	1.61	8.03	0.21
BP4-QT5	10.00	1.003	0.094	12.73	135.06	1.67	7.96	0.20
Average		1.003	0.095	12.77	133.40	1.66	7.95	0.26
Standard deviation		0.001	0.001	0.34	3.85	0.05	0.05	0.04

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 58.3 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
AMC-QT1	10.00	1.003	0.093	12.19	130.73	1.54	8.74	0.31
AMC-QT2	10.00	1.007	0.094	12.24	129.30	1.54	8.66	0.31
AMC-QT3	10.00	0.994	0.092	12.32	134.74	1.57	8.87	0.30
AMC-QT4	10.00	1.002	0.095	11.72	123.14	1.52	8.33	0.31
AMC-QT5	10.00	1.002	0.094	12.59	133.65	1.62	8.55	0.32
Average		1.002	0.094	12.21	130.31	1.56	8.63	0.31
Standard deviation		0.004	0.001	0.28	4.08	0.03	0.18	0.01

[a]At 0.2-percent strain.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 61.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BASF-QT1	10.00	1.001	0.087	13.94	160.09	1.82	9.23	0.31
BASF-QT2	10.00	1.004	0.088	13.59	153.83	1.89	8.80	0.32
BASF-QT3	10.00	1.004	0.088	13.39	151.60	1.84	8.70	0.32
BASF-QT4	10.00	1.005	0.089	13.33	149.03	1.81	8.54	0.31
BASF-QT5	10.00	1.005	0.091	13.51	147.71	1.83	8.56	0.32
Average		1.004	0.089	13.55	152.45	1.84	8.77	0.32
Standard deviation		0.001	0.001	0.21	4.36	0.03	0.25	0.00

[a]At 0.2-percent strain.

Table 8. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 59.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5255-QT1	10.00	1.005	0.087	12.96	147.91	1.76	8.62	0.31
5255-QT2	10.00	1.005	0.087	12.55	143.23	1.73	8.28	0.31
5255-QT3	10.00	1.005	0.088	12.96	146.41	1.76	8.51	0.31
5255-QT4	10.00	1.005	0.089	12.21	137.07	1.69	8.25	0.31
5255-QT5	10.00	1.005	0.087	12.65	144.14	1.74	8.42	0.31
Average		1.005	0.088	12.67	143.75	1.74	8.42	0.31
Standard deviation		0.000	0.001	0.28	3.73	0.03	0.14	0.00

[a]At 0.2-percent strain.

(e) IM7/5260 laminate; nominal fiber volume fraction, 58.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5260-QT1	10.00	1.011	0.090	12.94	142.19	1.68	8.48	0.30
5260-QT2	10.00	1.007	0.090	12.98	143.25	1.68	8.37	0.29
5260-QT3	10.00	1.004	0.092	12.39	134.14	1.63	8.21	0.29
5260-QT4	10.00	1.004	0.092	13.23	143.23	1.73	8.25	0.30
5260-QT5	10.00	1.004	0.091	12.08	132.23	1.61	8.22	0.30
Average		1.006	0.091	12.72	139.01	1.67	8.31	0.30
Standard deviation		0.003	0.001	0.42	4.81	0.04	0.10	0.00

[a]At 0.2-percent strain.

Table 9. Tension Properties for Notched Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 53.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BP4-HT1	10.00	3.001	0.097	0.5	17.06	58.62	0.71	7.90
BP4-HT2	10.00	3.003	0.097	0.5	15.37	52.76	0.69	7.65
BP4-HT3	10.00	3.002	0.096	0.5	15.83	54.94	0.69	7.94
Average		3.002	0.097	0.5	16.09	55.44	0.70	7.83
Standard deviation		0.001	0.000	0.0	0.72	2.42	0.01	0.13
BP4-HT4	10.00	1.498	0.097	0.25	8.78	60.45	0.77	7.76
BP4-HT5	10.00	1.499	0.097	0.25	9.08	62.45	0.81	7.64
BP4-HT6	10.00	1.498	0.096	0.25	8.81	61.23	0.77	7.72
Average		1.498	0.097	0.25	8.89	61.38	0.78	7.71
Standard deviation		0.000	0.000	0.00	0.14	0.82	0.02	0.05

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 58.3 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
AMC-HT1	10.00	3.003	0.095	0.5	14.74	51.56	0.64	8.32
AMC-HT2	10.00	3.004	0.095	0.5	16.08	56.45	0.67	8.42
AMC-HT3	10.00	3.002	0.094	0.5	15.80	55.88	0.68	8.26
Average		3.003	0.095	0.5	15.54	54.63	0.66	8.33
Standard deviation		0.001	0.000	0.0	0.58	2.18	0.02	0.07
AMC-HT4	10.00	1.501	0.096	0.25	8.76	60.70	0.78	8.02
AMC-HT5	10.00	1.501	0.095	0.25	9.16	64.05	0.82	8.02
AMC-HT6	10.00	1.500	0.094	0.25	9.02	63.89	0.78	8.30
Average		1.501	0.095	0.25	8.98	62.88	0.79	8.11
Standard deviation		0.000	0.001	0.00	0.17	1.54	0.02	0.13

[a]At 0.2-percent strain.

Table 9. Continued

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 61.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BASF-HT1	10.00	3.004	0.089	0.5	19.77	73.88	0.84	8.55
BASF-HT2	10.00	3.005	0.090	0.5	22.10	82.07	0.92	8.69
BASF-HT3	10.00	3.002	0.083	0.5	21.01	84.00	0.87	9.39
Average		3.004	0.087	0.5	20.96	79.98	0.88	8.88
Standard deviation		0.001	0.003	0.0	0.95	4.39	0.03	0.37
BASF-HT4	10.00	1.501	0.089	0.25	11.02	82.27	1.00	8.47
BASF-HT5	10.00	1.501	0.089	0.25	11.97	89.67	1.06	8.60
BASF-HT6	10.00	1.500	0.089	0.25	10.61	79.86	0.96	8.50
Average		1.501	0.089	0.25	11.20	83.93	1.01	8.52
Standard deviation		0.000	0.000	0.00	0.57	4.17	0.04	0.06

[a]At 0.2-percent strain.

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 59.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5255-HT1	10.00	3.003	0.088	0.5	16.16	61.16	0.70	8.68
5255-HT2	10.00	3.003	0.089	0.5	17.65	66.18	0.75	8.66
5255-HT3	10.00	3.002	0.088	0.5	16.55	62.86	0.71	8.65
Average		3.003	0.088	0.5	16.79	63.40	0.72	8.66
Standard deviation		0.000	0.000	0.0	0.63	2.08	0.02	0.01
5255-HT4	10.00	1.500	0.087	0.25	9.63	73.55	0.86	8.77
5255-HT5	10.00	1.501	0.089	0.25	9.67	72.40	0.86	8.64
5255-HT6	10.00	1.500	0.088	0.25	9.88	75.09	0.87	8.85
Average		1.500	0.088	0.25	9.73	73.68	0.86	8.75
Standard deviation		0.000	0.001	0.00	0.11	1.10	0.00	0.09

[a]At 0.2-percent strain.

Table 9. Concluded

(e) IM7/5260 laminate; nominal fiber volume fraction, 58.6 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5260-HT1	10.00	3.001	0.092	0.5	17.98	65.12	0.76	8.36
5260-HT2	10.00	3.006	0.091	0.5	17.29	63.21	0.73	8.48
5260-HT3	10.00	3.006	0.091	0.5	18.19	66.48	0.76	8.44
Average		3.004	0.091	0.5	17.82	64.94	0.75	8.43
Standard deviation		0.002	0.000	0.0	0.38	1.34	0.01	0.05
5260-HT4	10.00	1.505	0.090	0.25	10.05	74.58	0.86	8.50
5260-HT5	10.00	1.502	0.091	0.25	10.09	73.80	0.89	8.17
5260-HT6	10.00	1.501	0.091	0.25	9.84	72.04	0.86	8.14
Average		1.503	0.091	0.25	9.99	73.47	0.87	8.27
Standard deviation		0.002	0.001	0.00	0.11	1.06	0.01	0.16

[a]At 0.2-percent strain.

Table 10. Unnotched RTD Compression Properties for Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 52.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BP-C1	1.75	1.500	0.220	33.36	101.10	1.72	7.24	0.29
BP-C2	1.75	1.500	0.220	32.37	98.10	1.66	7.17	0.29
BP-C3	1.75	1.500	0.220	31.65	95.90		7.35	0.30
BP-C4	1.75	1.500	0.220	30.99	93.90		7.13	0.30
BP-C5	1.75	1.500	0.220	31.91	96.70	1.66	7.07	0.31
Average		1.500	0.220	32.06	97.14	1.68	7.19	0.30
Standard deviation . . .		0.000	0.000	0.79	2.40	0.03	0.10	0.01

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 55.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
AMC-C1	1.75	1.500	0.235	30.11	85.42	1.34	6.95	0.31
AMC-C2	1.75	1.502	0.236	30.30	85.47	1.33	7.10	0.30
AMC-C3	1.75	1.502	0.240	29.38	81.50	0.93	6.99	0.30
AMC-C4	1.75	1.503	0.240	30.94	85.78	1.38	6.99	0.30
Average		1.502	0.238	30.18	84.54	1.24	7.01	0.30
Standard deviation		0.001	0.002	0.56	1.76	0.18	0.06	0.01

[a]At 0.2-percent strain.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 58.0 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
BASF-C1	1.75	1.500	0.216	32.20	99.37	1.44	7.61	0.32
BASF-C2	1.75	1.501	0.216	31.09	95.89	1.39	7.56	0.32
BASF-C3	1.75	1.501	0.217	33.36	102.42	1.53	7.54	0.32
BASF-C4	1.75	1.501	0.217	33.47	102.75	1.53	7.47	0.32
BASF-C5	1.75	1.500	0.218	32.47	99.30	1.46	7.52	0.31
Average		1.501	0.217	32.52	99.95	1.47	7.54	0.32
Standard deviation		0.000	0.001	0.87	2.50	0.05	0.05	0.00

[a]At 0.2-percent strain.

Table 10. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 59.6 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5255-C1	10.00	1.501	0.216	30.69	94.65	1.45	7.42	0.31
5255-C2	10.00	1.501	0.215	30.71	95.17	1.45	7.43	0.31
5255-C3	10.00	1.501	0.216	29.25	90.23	1.38	7.38	0.32
5255-C4	10.00	1.502	0.214	31.38	97.62	1.51	7.46	0.31
5255-C5	10.00	1.502	0.214	31.37	97.59	1.51	7.45	0.32
Average		1.501	0.215	30.68	95.05	1.46	7.43	0.32
Standard deviation		0.000	0.001	0.77	2.70	0.05	0.03	0.00

[a]At 0.2-percent strain.

(e) IM7/5260 laminate; nominal fiber volume fraction, 60.0 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi	Poisson's ratio[a]
5260-C1	1.75	1.506	0.216	37.97	116.73	1.83	7.45	0.33
5260-C2	1.75	1.506	0.216	38.17	117.33	1.83	7.53	0.32
5260-C3	1.75	1.505	0.216	39.26	120.76	1.91	7.46	0.33
5260-C4	1.75	1.506	0.216	38.66	118.85	1.89	7.33	0.34
5260-C5	1.75	1.505	0.215	37.63	116.29	1.79	7.50	0.33
Average		1.506	0.216	38.34	117.99	1.85	7.45	0.33
Standard deviation		0.000	0.000	0.57	1.63	0.04	0.07	0.01

[a]At 0.2-percent strain.

Table 11. Compression Properties for Notched Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 53.7 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BP-HC4	10.00	3.004	0.240	0.25	37.01	51.34	0.71	7.62
BP-HC5	10.00	3.006	0.242	0.25	37.59	51.68	0.72	7.50
BP-HC6	10.00	3.006	0.242	0.25	37.18	51.11	0.71	7.49
Average		3.005	0.241	0.25	37.26	51.38	0.71	7.54
Standard deviation		0.001	0.001	0.00	0.24	0.23	0.00	0.06
BP-HC7	10.00	3.004	0.240	0.50	31.15	43.21	0.58	7.82
BP-HC8	10.00	3.004	0.240	0.50	30.63	42.49	0.57	7.69
BP-HC9	10.00	3.005	0.240	0.50	31.09	43.11	0.58	7.76
Average		3.004	0.240	0.50	30.96	42.94	0.57	7.76
Standard deviation		0.000	0.000	0.00	0.23	0.32	0.00	0.05
BP-HC1	10.00	5.006	0.242	1.00	44.24	36.52	0.51	7.43
BP-HC2	10.00	5.003	0.241	1.00	45.38	37.64	0.23	7.32
BP-HC3	10.00	5.004	0.243	1.00	44.64	36.71	0.51	7.37
Average		5.004	0.242	1.00	44.75	36.96	0.42	7.37
Standard deviation		0.001	0.001	0.00	0.47	0.49	0.13	0.04

[a]At 0.2-percent strain.

Table 11. Continued

(b) IM7/X1845 laminate; nominal fiber volume fraction, 55.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
AMC-HC4	10.00	3.003	0.242	0.25	35.18	48.41	0.66	7.46
AMC-HC5	10.00	3.004	0.244	0.25	36.35	49.59	0.69	7.36
AMC-HC6	10.00	3.005	0.242	0.25	33.61	46.22	0.65	7.26
Average		3.004	0.243	0.25	35.05	48.07	0.67	7.36
Standard deviation		0.001	0.001	0.00	1.12	1.40	0.02	0.08
AMC-HC7	10.00	3.003	0.240	0.50	26.94	37.38	0.48	7.72
AMC-HC8	10.00	3.003	0.242	0.50	28.59	39.34	0.51	7.74
AMC-HC9	10.00	3.004	0.240	0.50	26.44	36.67	0.48	7.60
Average		3.003	0.241	0.50	27.32	37.80	0.49	7.69
Standard deviation		0.000	0.001	0.00	0.92	1.13	0.01	0.06
AMC-HC1	10.00	5.004	0.239	1.00	38.19	31.93	0.44	7.29
AMC-HC2	10.00	5.005	0.241	1.00	36.18	30.00	0.42	7.21
AMC-HC3	10.00	5.006	0.245	1.00	36.64	29.88	0.39	7.08
Average		5.005	0.242	1.00	37.00	30.60	0.42	7.19
Standard deviation		0.001	0.002	0.00	0.86	0.94	0.02	0.09

[a]At 0.2-percent strain.

Table 11. Continued

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 61.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BASF-HC4	10.00	3.005	0.219	0.25	33.12	50.32	0.45	7.98
BASF-HC5	10.00	3.004	0.221	0.25	33.99	51.20	0.66	7.92
BASF-HC6	10.00	3.005	0.219	0.25	33.49	50.89	0.65	7.96
Average		3.005	0.220	0.25	33.53	50.80	0.59	7.95
Standard deviation		0.000	0.001	0.00	0.36	0.36	0.10	0.03
BASF-HT7	10.00	3.003	0.217	0.50	27.77	42.62	0.52	8.32
BASF-HT8	10.00	3.003	0.220	0.50	28.21	42.70	0.20	8.20
BASF-HT9	10.00	3.003	0.219	0.50	28.71	43.66	0.54	8.20
Average		3.003	0.219	0.50	28.23	42.99	0.42	8.24
Standard deviation		0.000	0.001	0.00	0.38	0.47	0.16	0.06
BASF-HC1	10.00	5.004	0.214	1.00	37.08	34.63	0.43	8.01
BASF-HC2	10.00	5.004	0.221	1.00	40.10	36.26	0.47	7.79
BASF-HC3	10.00	5.003	0.223	1.00	38.33	34.36	0.45	7.71
Average		5.004	0.219	1.00	38.50	35.08	0.45	7.84
Standard deviation		0.000	0.004	0.00	1.24	0.84	0.02	0.13

[a]At 0.2-percent strain.

Table 11. Continued

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 60.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5255-HC4	10.00	3.006	0.222	0.25	29.59	44.34	0.60	7.72
5255-HC5	10.00	3.005	0.224	0.25	31.25	46.43	0.63	7.76
Average		3.006	0.223	0.25	30.42	45.39	0.61	7.74
Standard deviation		0.001	0.001	0.00	0.83	1.04	0.02	0.02
5255-HC7	10.00	3.003	0.222	0.50	24.38	36.57	0.48	7.95
5255-HC8	10.00	3.005	0.224	0.50	24.99	37.13	0.48	7.97
5255-HC9	10.00	3.006	0.223	0.50	25.95	38.71	0.51	7.90
Average		3.005	0.223	0.50	25.11	37.47	0.49	7.94
Standard deviation		0.001	0.001	0.00	0.65	0.91	0.01	0.03
5255-HC1	10.00	5.007	0.216	1.00	40.09	37.07	0.49	6.92
5255-HC2	10.00	5.006	0.217	1.00	40.11	36.92	0.49	7.68
5255-HC3	10.00	5.007	0.215	1.00	38.43	35.70	0.47	7.69
Average		5.007	0.216	1.00	39.54	36.56	0.48	7.43
Standard deviation		0.000	0.001	0.00	0.79	0.61	0.01	0.36

[a]At 0.2-percent strain.

Table 11. Concluded

(e) IM7/5260 laminate; nominal fiber volume fraction, 57.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5260-HC4	10.00	3.000	0.225	0.25	36.86	54.61	0.72	8.03
5260-HC5	10.00	3.000	0.230	0.25	37.34	54.12	0.72	8.03
5260-HC6	10.00	3.001	0.226	0.25	36.34	53.58	0.70	8.09
Average		3.000	0.227	0.25	36.85	54.10	0.71	8.05
Standard deviation		0.000	0.002	0.00	0.41	0.42	0.01	0.03
5260-HC7	10.00	3.002	0.225	0.50	30.75	45.52	0.58	8.26
5260-HC8	10.00	3.002	0.230	0.50	31.27	45.30	0.58	8.17
5260-HC9	10.00	3.000	0.225	0.50	31.29	46.35	0.58	8.34
Average		3.001	0.227	0.50	31.10	45.72	0.58	8.26
Standard deviation		0.001	0.002	0.00	0.25	0.45	0.00	0.07
5260-HC1	10.00	5.007	0.227	1.00	47.29	41.61	0.55	7.74
5260-HC2	10.00	5.004	0.227	1.00	47.06	41.43	0.55	7.77
5260-HC3	10.00	5.008	0.228	1.00	47.24	41.37	0.55	7.79
Average		5.006	0.227	1.00	47.20	41.47	0.55	7.76
Standard deviation		0.002	0.000	0.00	0.10	0.10	0.00	0.02

[a]At 0.2-percent strain.

Table 12. Compression Properties for Notched Quasi-Isotropic Laminates Under Hot, Wet Conditions

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 52.4 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BP-HC10	10.00	3.005	0.242	0.25	29.09	40.00	0.56	7.42
BP-HC11	10.00	3.004	0.245	0.25	30.10	40.90	0.58	7.42
BP-HC12	10.00	3.005	0.243	0.25	31.08	42.57	0.59	7.66
Average		3.005	0.243	0.25	30.09	41.16	0.58	7.50
Standard deviation		0.000	0.001	0.00	0.81	1.06	0.01	0.11

[a]At 0.2-percent strain.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 55.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
AMC-HC10	10.00	3.004	0.241	0.25	24.45	33.77	0.46	7.34
AMC-HC11	10.00	3.002	0.242	0.25	24.58	33.83	0.45	7.44
AMC-HC12	10.00	3.003	0.237	0.25	24.23	34.04	0.41	8.60
Average		3.003	0.240	0.25	24.42	33.88	0.44	7.79
Standard deviation		0.001	0.002	0.00	0.14	0.12	0.02	0.57

[a]At 0.2-percent strain.

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 58.0 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BASF-HC10	10.00	3.003	0.220	0.25	28.49	43.12	0.57	8.02
BASF-HC11	10.00	3.004	0.222	0.25	28.31	42.45	0.56	7.97
BASF-HC12	10.00	3.009	0.222	0.25	28.18	42.18	0.54	7.89
Average		3.005	0.221	0.25	28.32	42.58	0.56	7.96
Standard deviation		0.003	0.001	0.00	0.13	0.40	0.01	0.05

[a]At 0.2-percent strain.

Table 12. Concluded

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 60.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5255-HC10	10.00	3.001	0.215	0.25	27.89	43.23	0.56	8.23
5255-HC11	10.00	3.005	0.221	0.25	27.49	41.39	0.55	7.95
Average		3.003	0.218	0.25	27.69	42.31	0.56	8.09
Standard deviation		0.002	0.003	0.00	0.20	0.92	0.00	0.14

[a]At 0.2-percent strain.

(e) IM7/5260 laminate; nominal fiber volume fraction, 57.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5260-HC10	10.00	3.007	0.225	0.25	0.00	45.71	0.61	7.81
5260-HC11	10.00	2.980	0.230	0.25	0.00	48.30	0.64	7.84
5260-HC12	10.00	2.982	0.229	0.25	0.00	47.25	0.63	7.99
Average		2.990	0.228	0.25	0.00	47.09	0.63	7.88
Standard deviation		0.012	0.002	0.00	0.00	1.06	0.01	0.08

[a]At 0.2-percent strain.

Table 13. Compression Properties for Impacted Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 54.2 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BP-CAI1[b]	10.00	5.006	0.245	2.18	44.39	36.19	0.51	7.12
BP-CAI2[b]	10.00	5.004	0.244	2.46	46.30	37.92	0.53	7.15
BP-CAI3[b]	10.00	5.004	0.243	2.41	42.71	35.12	0.48	7.26
Average		5.005	0.244	2.35	44.46	36.41	0.51	7.18
Standard deviation		0.001	0.001	0.12	1.47	1.15	0.02	0.06
BP-CAI4[c]	10.00	5.004	0.244	3.95	35.71	29.25	0.40	7.26
BP-CAI5[c]	10.00	5.005	0.245	3.91	36.71	29.94	0.41	7.30
BP-CAI6[c]	10.00	5.005	0.244	3.97	37.72	30.89	0.43	7.24
Average		5.005	0.244	3.94	36.72	30.03	0.41	7.26
Standard deviation		0.000	0.000	0.02	0.82	0.67	0.01	0.03
BP-DWCAI[d]	10.00	4.995	0.243	1.97	48.38	39.86	0.57	7.28

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.
[d]Impacted with drop weight at 1500 in-lb/in.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 56.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
AMC-CAI1[b]	10.00	5.001	0.234	2.32	41.46	35.43	0.49	7.39
AMC-CAI2[b]	10.00	4.999	0.235	2.49	42.59	36.25	0.50	7.36
AMC-CAI3[b]	10.00	5.000	0.233	2.85	42.50	36.48	0.50	7.39
Average		5.000	0.234	2.55	42.18	36.05	0.50	7.38
Standard deviation		0.001	0.001	0.22	0.51	0.45	0.00	0.01
AMC-CAI4[c]	10.00	5.001	0.233	4.30	34.12	29.28	0.40	7.43
AMC-CAI5[c]	10.00	5.000	0.233	3.84	33.54	28.79	0.39	7.43
AMC-CAI6[c]	10.00	5.000	0.236	4.65	31.74	26.90	0.37	7.33
Average		5.000	0.234	4.26	33.13	28.32	0.39	7.40
Standard deviation		0.000	0.001	0.33	1.01	1.03	0.01	0.05
AMC-DWCAI[d]	10.00	5.000	0.239	1.67	49.02	41.02	0.59	7.21

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.
[d]Impacted with drop weight at 1500 in-lb/in.

Table 13. Continued

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 59.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BASF-CAI1[b]	10.00	5.005	0.218	2.12	36.36	33.32	0.43	7.86
BASF-CAI2[b]	10.00	5.004	0.218	2.01	35.97	32.97	0.43	7.79
BASF-CAI3[b]	10.00	5.006	0.219	2.01	37.40	34.11	0.44	7.81
Average		5.005	0.218	2.05	36.57	33.47	0.43	7.82
Standard deviation		0.001	0.000	0.05	0.60	0.48	0.00	0.03
BASF-CAI4[c]	10.00	5.007	0.218	3.34	31.28	28.66	0.37	7.80
BASF-CAI5[c]	10.00	5.007	0.219	4.22	29.31	26.73	0.35	7.72
BASF-CAI6[c]	10.00	5.006	0.219	4.03	28.24	25.76	0.34	7.74
Average		5.007	0.219	3.86	29.61	27.05	0.35	7.75
Standard deviation		0.000	0.000	0.38	1.26	1.21	0.01	0.03
BASF-DWCAI[d]	10.00	4.996	0.219	1.80	46.15	42.18	0.56	7.72

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.
[d]Impacted with drop weight at 1500 in-lb/in.

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 60.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5255-CAI1[b]	10.00	5.005	0.213	1.96	35.03	32.86	0.43	7.80
5255-CAI2[b]	10.00	5.005	0.212	2.02	36.70	34.59	0.45	7.87
5255-CAI3[b]	10.00	5.007	0.214	1.98	34.12	31.84	0.40	7.82
Average		5.006	0.213	1.99	35.28	33.10	0.43	7.83
Standard deviation		0.001	0.001	0.02	1.07	1.14	0.02	0.03
5255-CAI4[c]	10.00	5.008	0.214	3.42	30.78	28.72	0.37	7.76
5255-CAI5[c]	10.00	5.005	0.215	3.23	31.75	29.51	0.38	7.77
5255-CAI6[c]	10.00	5.009	0.215	3.42	31.79	29.52	0.39	7.76
Average		5.007	0.215	3.36	31.44	29.25	0.38	7.76
Standard deviation		0.002	0.000	0.09	0.47	0.37	0.01	0.00

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

Table 13. Concluded

(d) IM7/5260 laminate; nominal fiber volume fraction, 57.1 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5260-CAI1[b]	10.00	5.002	0.224	2.77	36.93	32.96	0.43	7.79
5260-CAI2[b]	10.00	4.999	0.223	2.39	35.34	31.70	0.41	7.84
5260-CAI3[b]	10.00	5.000	0.225	2.74	35.58	31.63	0.41	7.71
Average		5.000	0.224	2.63	35.95	32.10	0.42	7.78
Standard deviation		0.001	0.001	0.17	0.70	0.61	0.01	0.05
5260-CAI4[c]	10.00	5.002	0.224	4.26	29.84	26.63	0.35	7.72
5260-CAI5[c]	10.00	5.001	0.225	4.58	25.94	23.05	0.30	7.70
5260-CAI6[c]	10.00	5.000	0.225	4.75	25.79	22.92	0.30	7.66
Average		5.001	0.225	4.53	27.19	24.20	0.32	7.69
Standard deviation		0.001	0.000	0.20	1.88	1.72	0.02	0.02
5260-DWCAI[d]	10.00	5.003	0.227	1.75	46.64	41.07	0.54	7.89

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.
[d]Impacted with drop weight at 1500 in-lb/in.

Table 14. Compression Properties for Impacted Hot, Wet Quasi-Isotropic Laminates

(a) IM7/E7T1-2 laminate; nominal fiber volume fraction, 53.7 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BP-CAI7[b]	10.00	5.003	0.244	2.25	40.19	32.92	0.47	7.35
BP-CAI8[b]	10.00	5.005	0.244	2.58	38.26	31.33	0.45	7.24
BP-CAI9[b]	10.00	5.004	0.244	2.01	44.44	36.40	0.52	7.06
Average		5.004	0.244	2.28	40.96	33.55	0.48	7.22
Standard deviation		0.001	0.000	0.23	2.58	2.12	0.03	0.12
BP-CAI10[c]	10.00	5.003	0.246	4.1	31.57	25.65	0.36	7.32
BP-CAI11[c]	10.00	5.005	0.244	4.95	32.07	26.26	0.37	7.41
BP-CAI12[c]	10.00	5.006	0.245	3.81	34.94	28.49	0.40	7.33
Average		5.005	0.245	4.29	32.86	26.80	0.38	7.35
Standard deviation		0.001	0.001	0.48	1.48	1.22	0.02	0.04

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

(b) IM7/X1845 laminate; nominal fiber volume fraction, 55.7 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
AMC-CAI7[b]	10.00	5.005	0.233	2.47	35.22	30.20	0.42	7.52
AMC-CAI8[b]	10.00	5.003	0.233	2.74	35.36	30.33	0.42	7.54
AMC-CAI9[b]	10.00	5.006	0.240	2.39	36.36	30.26	0.43	7.25
Average		5.005	0.235	2.53	35.64	30.26	0.42	7.44
Standard deviation		0.001	0.003	0.15	0.51	0.05	0.00	0.13
AMC-CAI10[c]	10.00	5.004	0.242	3.96	30.25	24.98	0.35	7.26
AMC-CAI11[c]	10.00	5.005	0.240	4.24	30.21	25.15	0.36	7.19
AMC-CAI12[c]	10.00	5.006	0.241	4.31	28.52	23.64	0.33	7.27
Average		5.005	0.241	4.17	29.66	24.59	0.35	7.24
Standard deviation		0.001	0.001	0.15	0.81	0.68	0.01	0.04

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

Table 14. Continued

(c) G40-800X/5255-3 laminate; nominal fiber volume fraction, 58.9 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
BASF-CAI7[b]	10.00	5.006	0.223	2.24	33.81	30.29	0.39	7.91
BASF-CAI8[b]	10.00	5.007	0.225	2.23	33.50	29.74	0.39	7.73
BASF-CAI9[b]	10.00	5.006	0.221	2.21	32.16	29.07	0.38	7.89
Average		5.006	0.223	2.23	33.16	29.70	0.39	7.84
Standard deviation		0.000	0.002	0.01	0.72	0.50	0.00	0.08
BASF-CAI10[c]	10.00	5.007	0.222	3.72	27.61	24.84	0.32	7.83
BASF-CAI11[c]	10.00	5.005	0.222	3.41	28.43	25.59	0.33	7.86
BASF-CAI12[c]	10.00	5.005	0.224	3.62	28.22	25.17	0.33	7.70
Average		5.006	0.223	3.58	28.09	25.20	0.33	7.80
Standard deviation		0.001	0.001	0.13	0.35	0.31	0.00	0.07

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

(d) IM7/5255-3 laminate; nominal fiber volume fraction, 59.8 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5255-CAI7[b]	10.00	5.007	0.219	2.02	34.09	31.09	0.41	7.89
5255-CAI8[b]	10.00	5.008	0.217	4.39	27.27	25.09	0.33	7.87
5255-CAI9[b]	10.00	4.998	0.216	2.02	32.87	30.45	0.40	7.81
Average		5.004	0.217	2.81	31.41	28.88	0.38	7.86
Standard deviation		0.004	0.001	1.12	2.97	2.69	0.04	0.03
5255-CAI10[c]	10.00	5.005	0.218	3.47	28.17	25.82	0.34	7.84
5233-CAI11[c]	10.00	5.008	0.216	3.41	28.73	26.56	0.34	7.94
5255-CAI12[c]	10.00	5.007	0.217	3.66	28.98	26.97	0.34	7.96
Average		5.007	0.217	3.51	28.63	26.35	0.34	7.91
Standard deviation		0.001	0.001	0.11	0.34	0.38	0.00	0.05

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

Table 14. Concluded

(e) IM7/5260 laminate; nominal fiber volume fraction, 57.5 percent

Specimen ID	Length, in.	Width, in.	Thickness, in.	Damage area, in^2	Failure load, kips	Failure stress, ksi	Failure strain, percent	Modulus,[a] Msi
5260-CAI7[b]	10.00	5.003	0.225	2.95	29.94	26.60	0.34	7.98
5260-CAI8[b]	10.00	5.004	0.226	2.88	31.39	27.76	0.36	7.91
5260-CAI9[b]	10.00	5.005	0.225	2.9	32.38	28.75	0.37	7.94
Average		5.004	0.225	2.91	31.24	27.70	0.36	7.94
Standard deviation		0.001	0.000	0.03	1.00	0.88	0.01	0.03
5260-CAI10[c]	10.00	5.003	0.227	4.9	25.84	22.75	0.30	7.77
5260-CAI11[c]	10.00	5.004	0.225	4.71	26.21	23.28	0.30	8.01
5260-CAI12[c]	10.00	5.004	0.226	4.75	25.94	22.94	0.30	7.93
Average		5.004	0.226	4.79	26.00	22.99	0.30	7.90
Standard deviation		0.000	0.001	0.08	0.16	0.22	0.00	0.10

[a]At 0.2-percent strain.
[b]Impacted with air gun at 1000 in-lb/in.
[c]Impacted with air gun at 1500 in-lb/in.

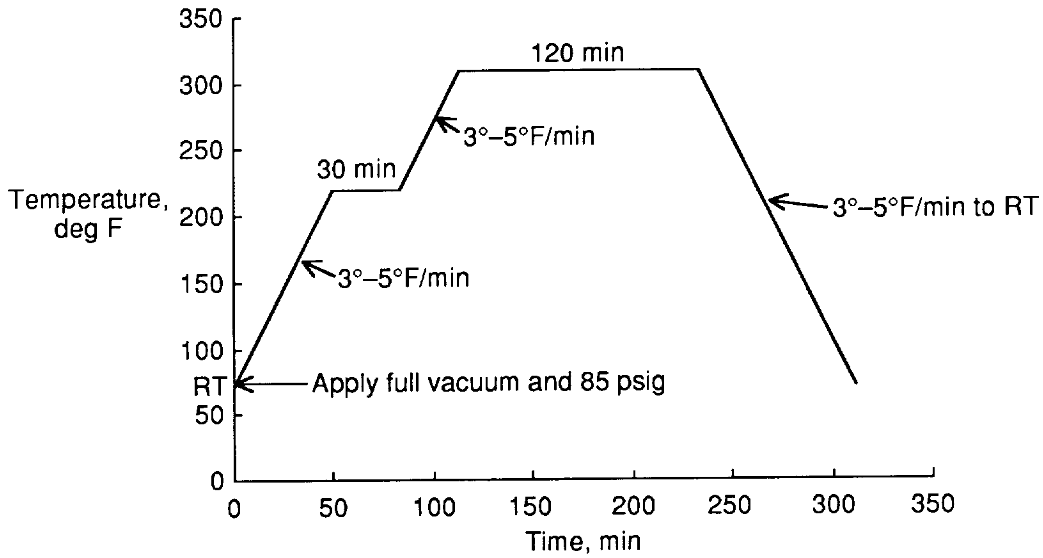


Figure 1. Cure cycle for IM7/E7T1-2 laminate. RT indicates room temperature.

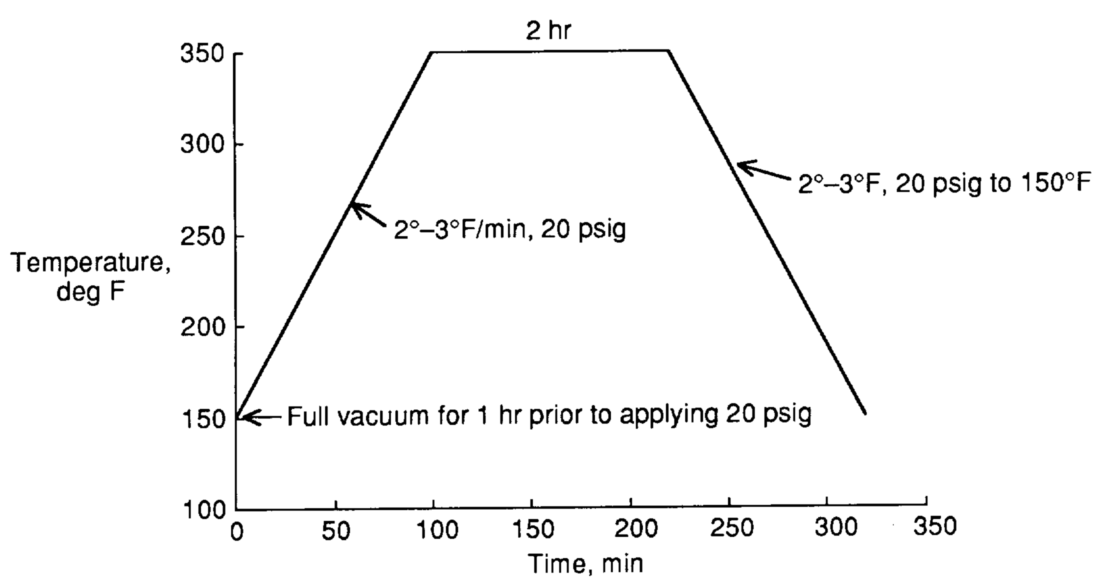


Figure 2. Cure cycle for IM7/X1845 laminate.

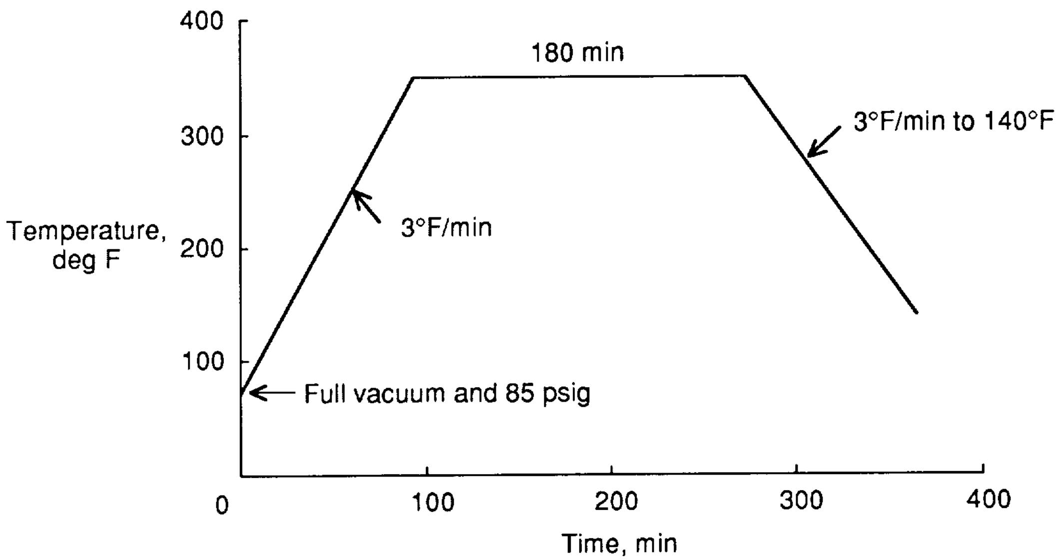


Figure 3. Cure cycle for IM7/5255-3 and G40-800/5255-3 laminates.

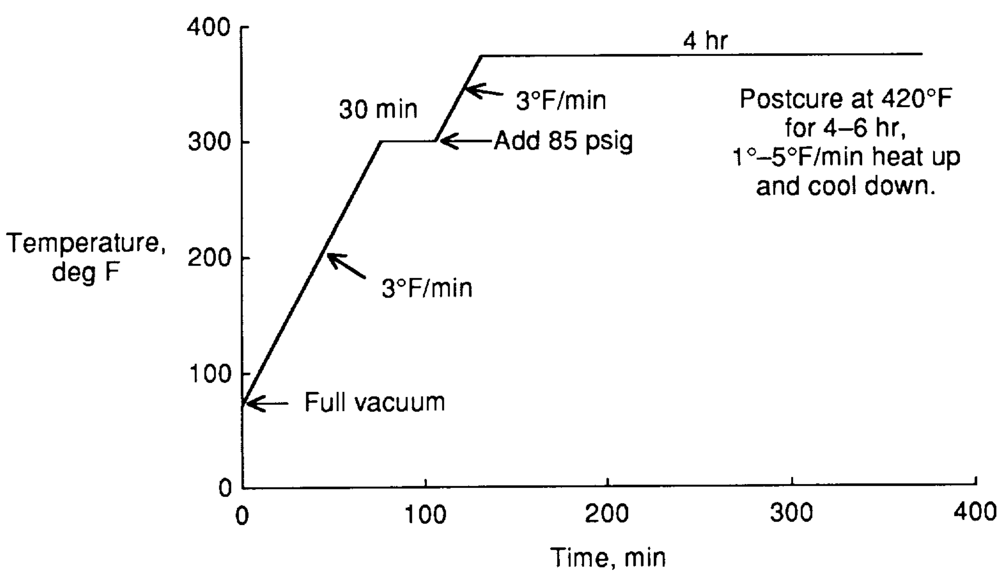
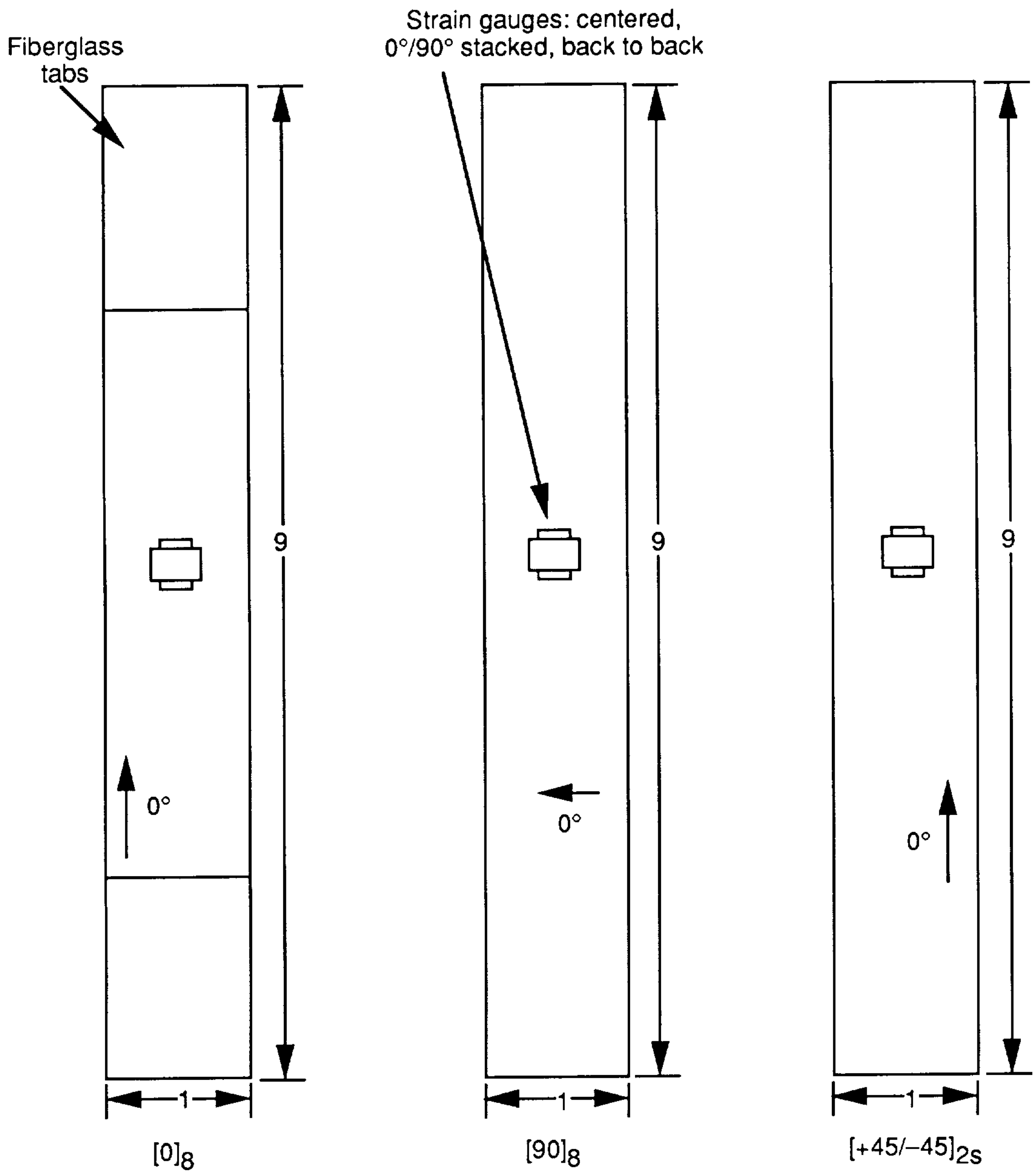
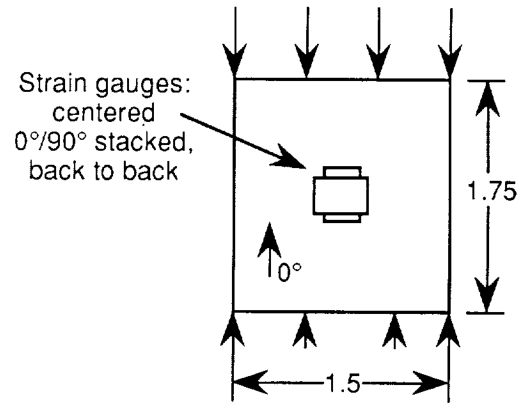


Figure 4. Cure cycle for IM7/5260 laminate.

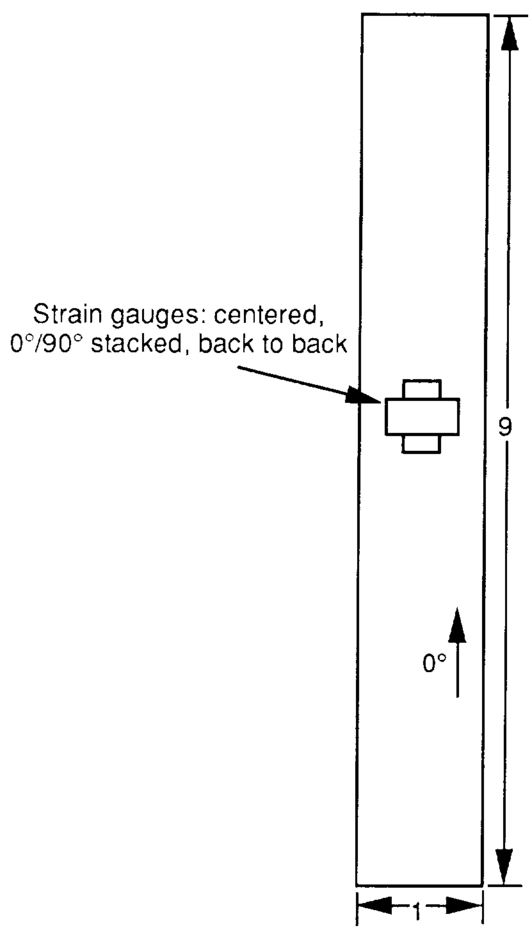


(a) Ply-level tension specimens.

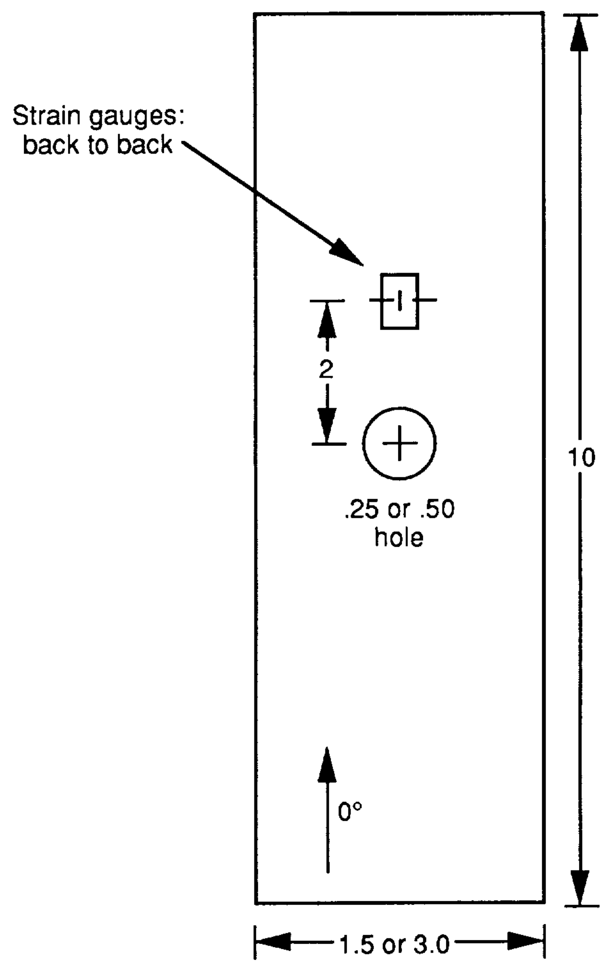
Figure 5. Specimen configurations. All dimensions are in inches.



(b) Short-block compression specimen.

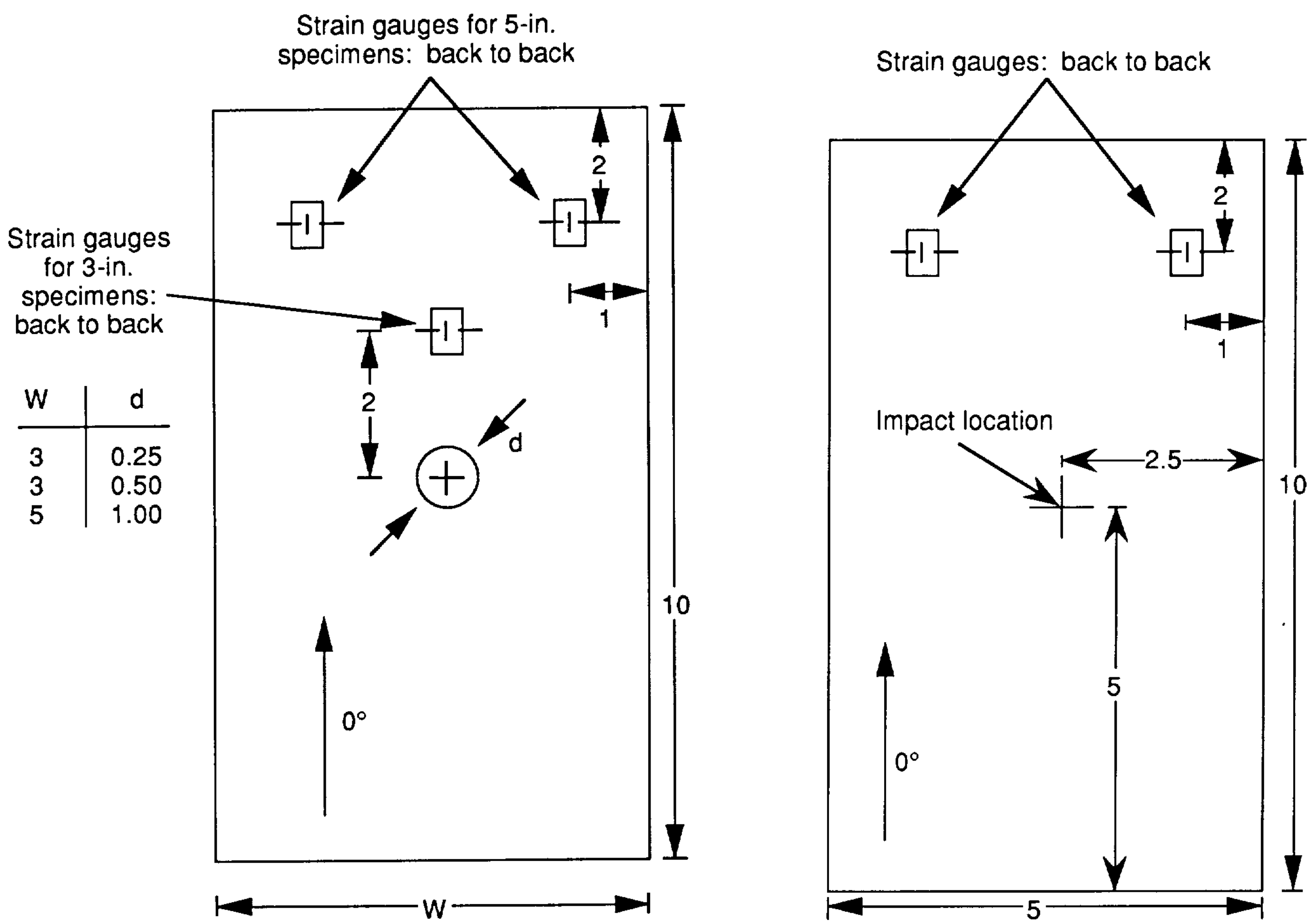


(c) Unnotched tension specimen for quasi-isotropic laminates.



(d) Open-hole tension specimens.

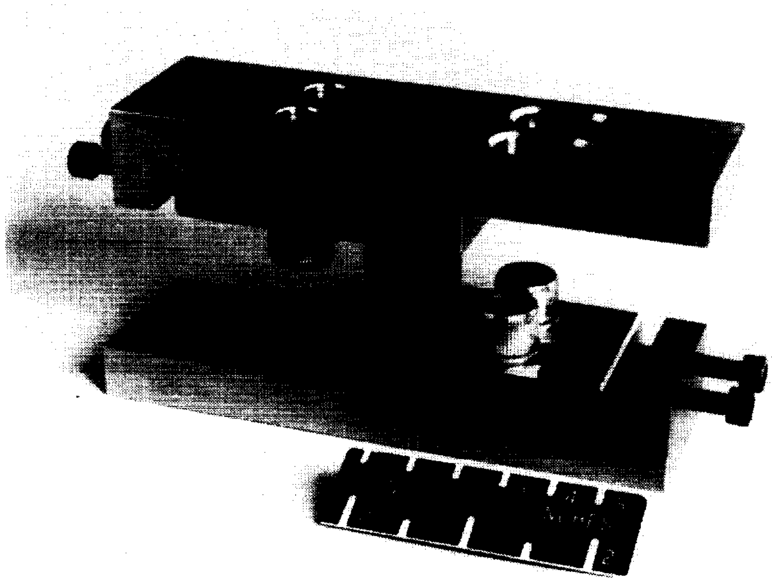
Figure 5. Continued.



(e) Open-hole compression specimens.

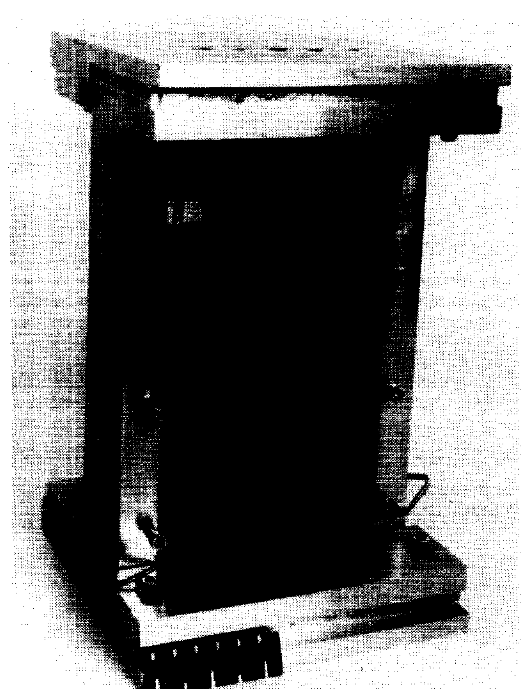
(f) Compression-after-impact specimens.

Figure 5. Concluded.



L-89-3310

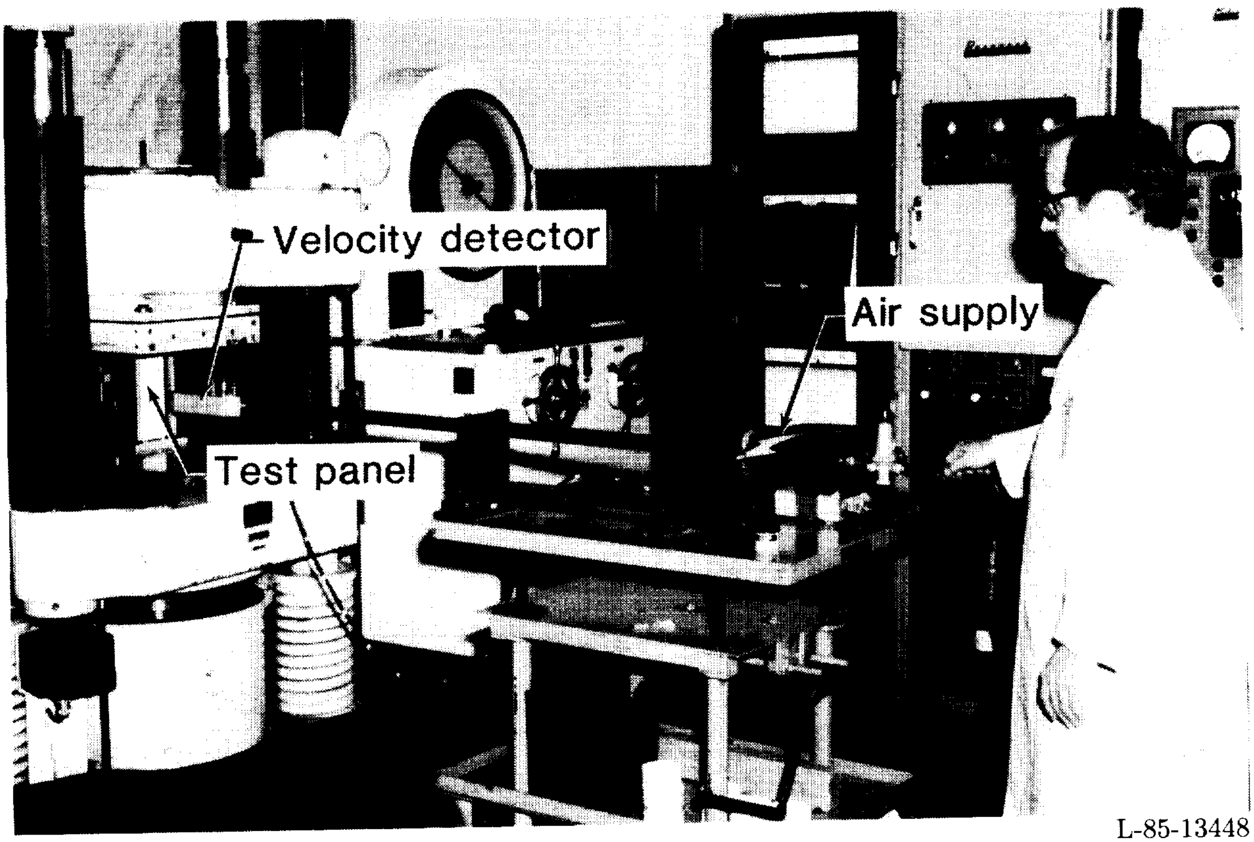
(a) Short-block compression fixture.



L-85-11872

(b) Compression-after-impact test fixture.

Figure 6. Compression test fixtures.



L-85-13448

Figure 7. Impact test apparatus.

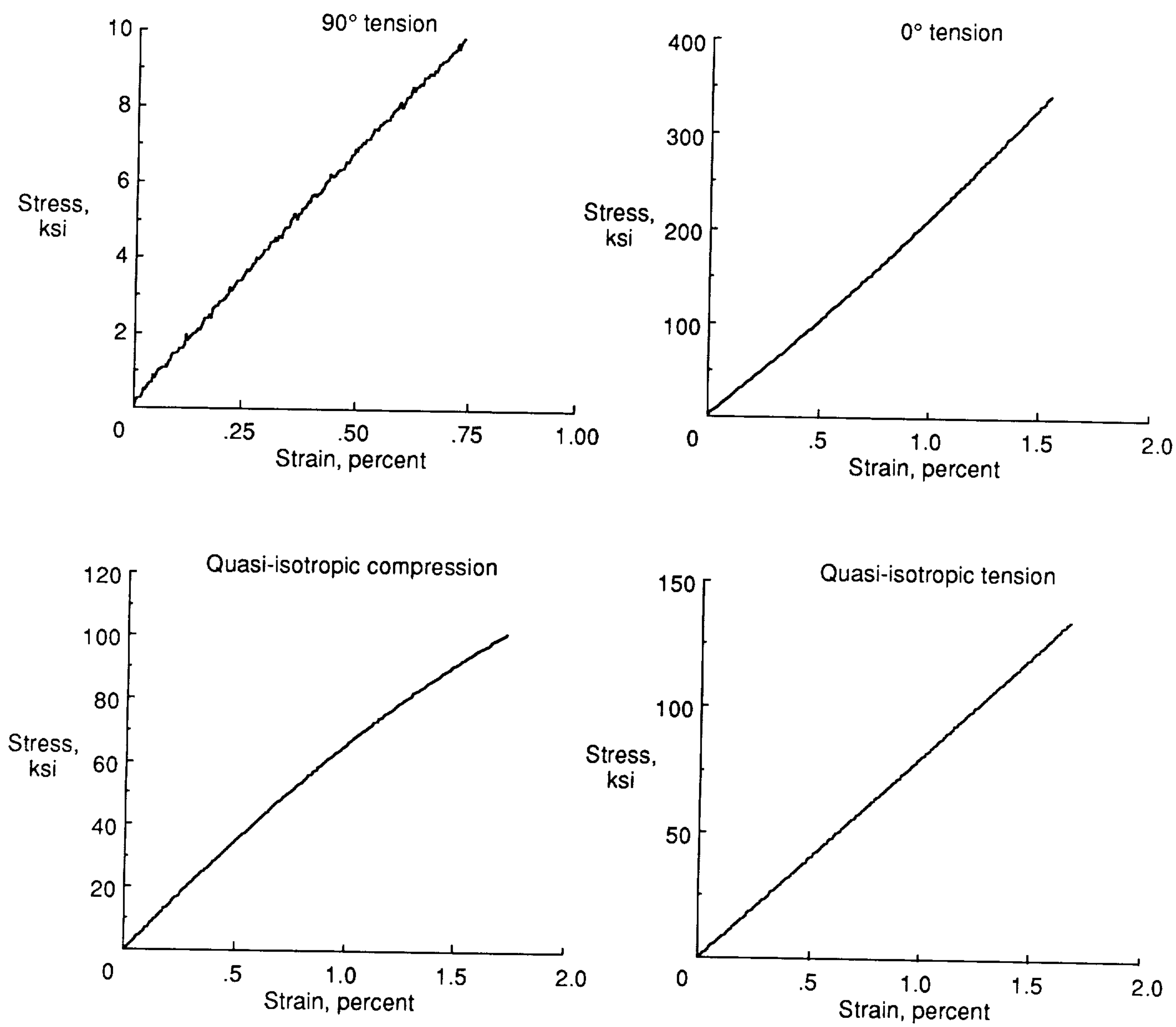


Figure 8. Typical stress-strain plots for IM7/E7T1-2 laminates.

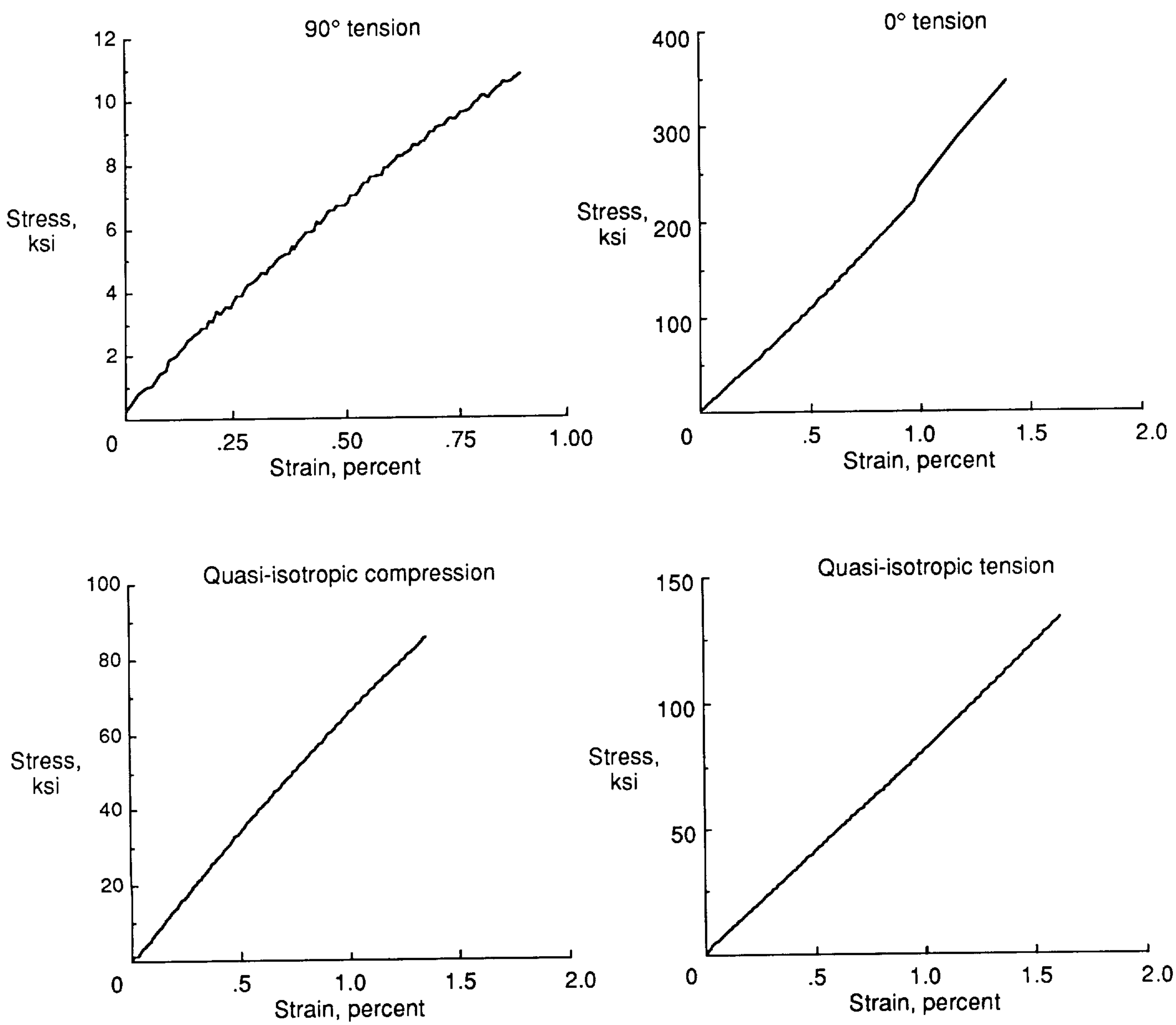


Figure 9. Typical stress-strain plots for IM7/X1845 laminates.

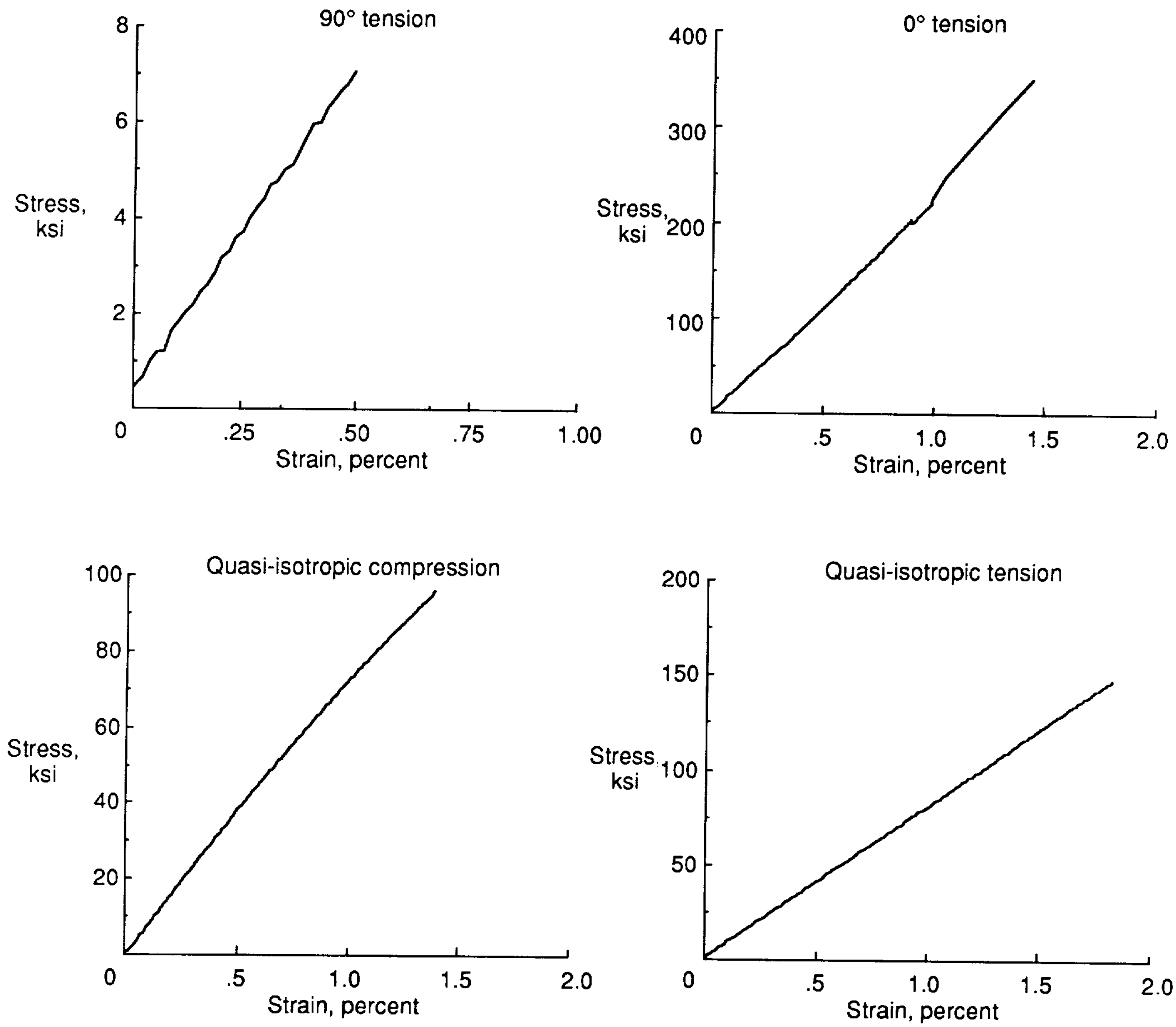


Figure 10. Typical stress-strain plots for G40-800X/5255-3 laminates.

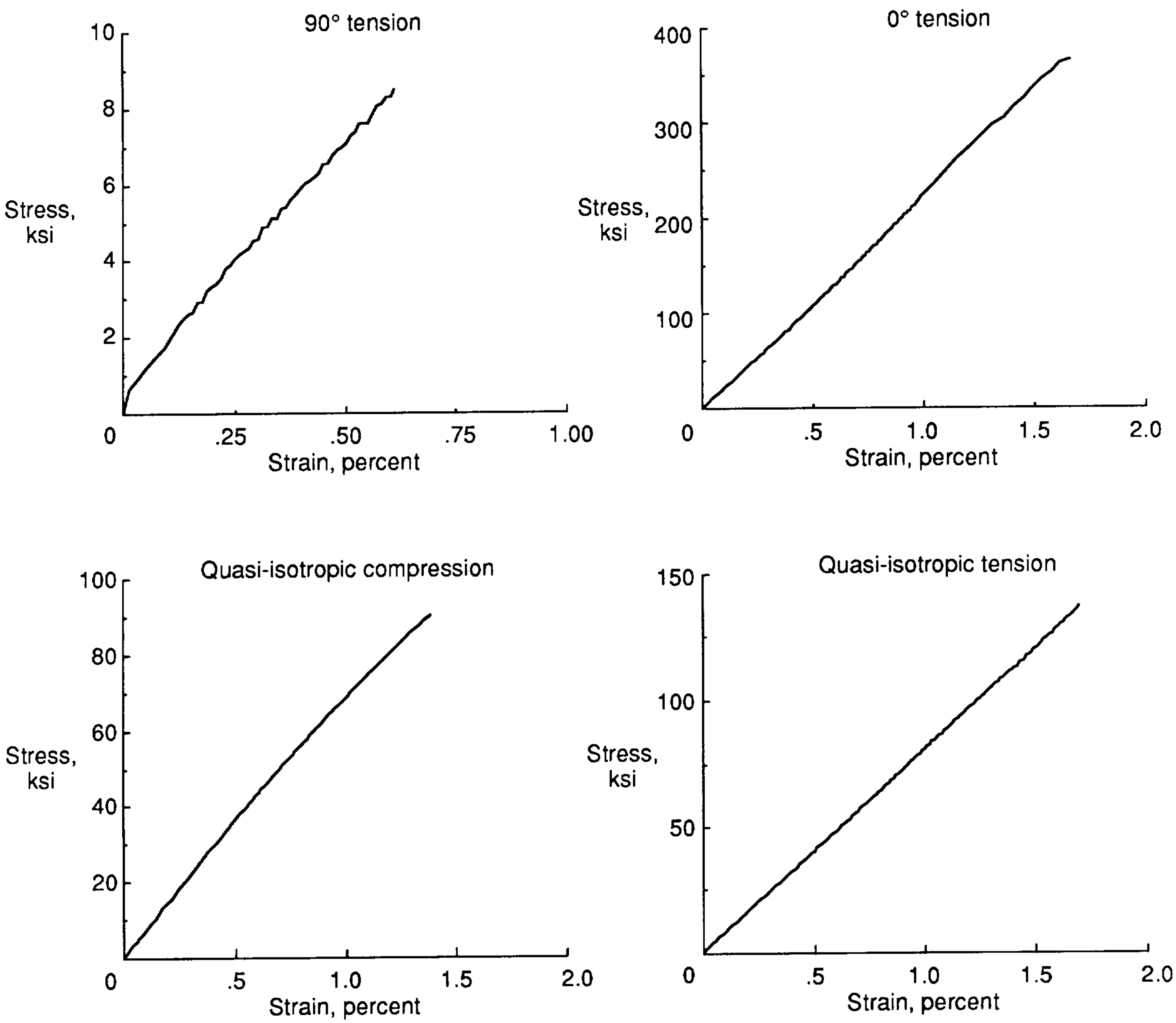


Figure 11. Typical stress-strain plots for IM7/5255-3 laminates.

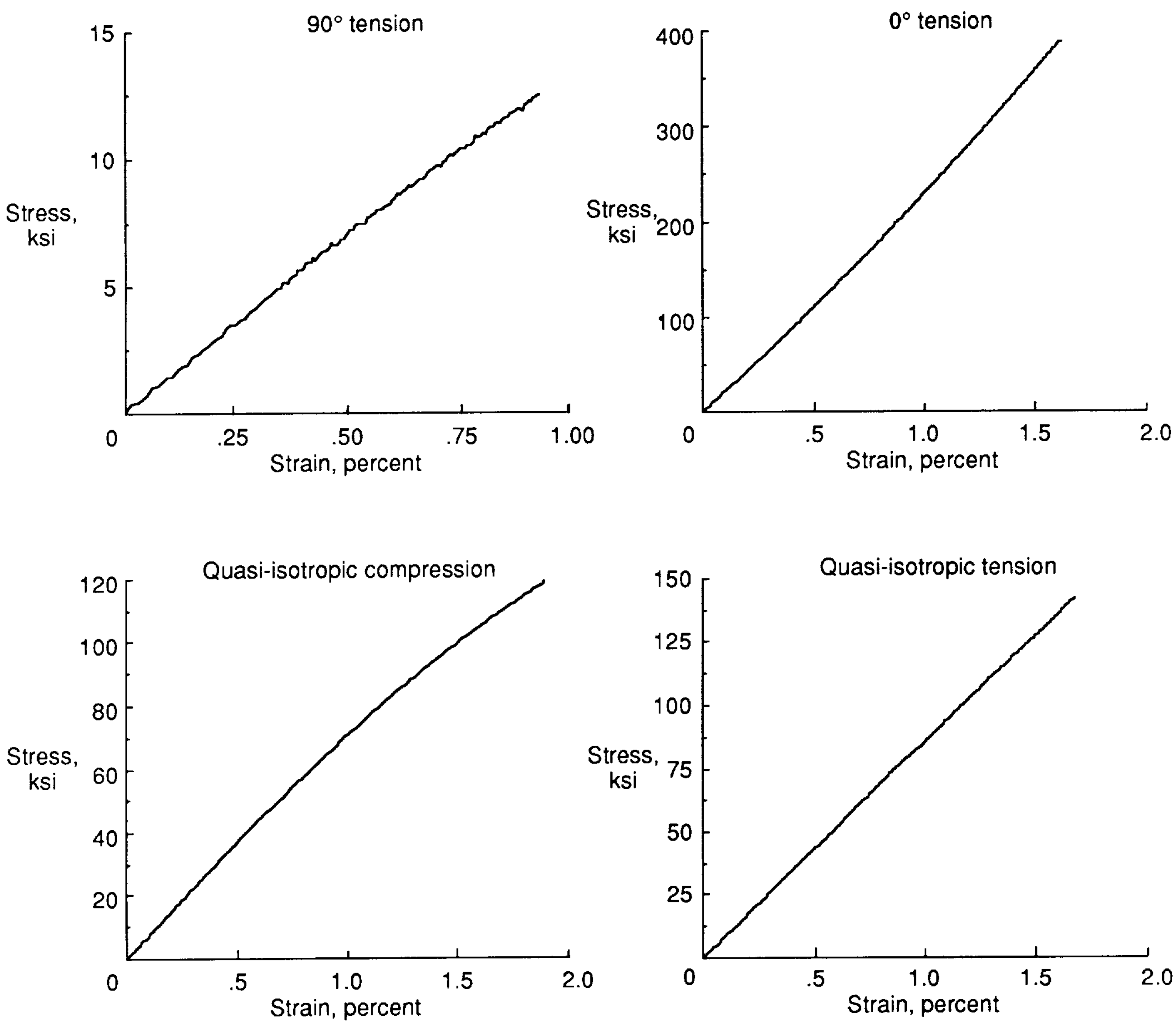
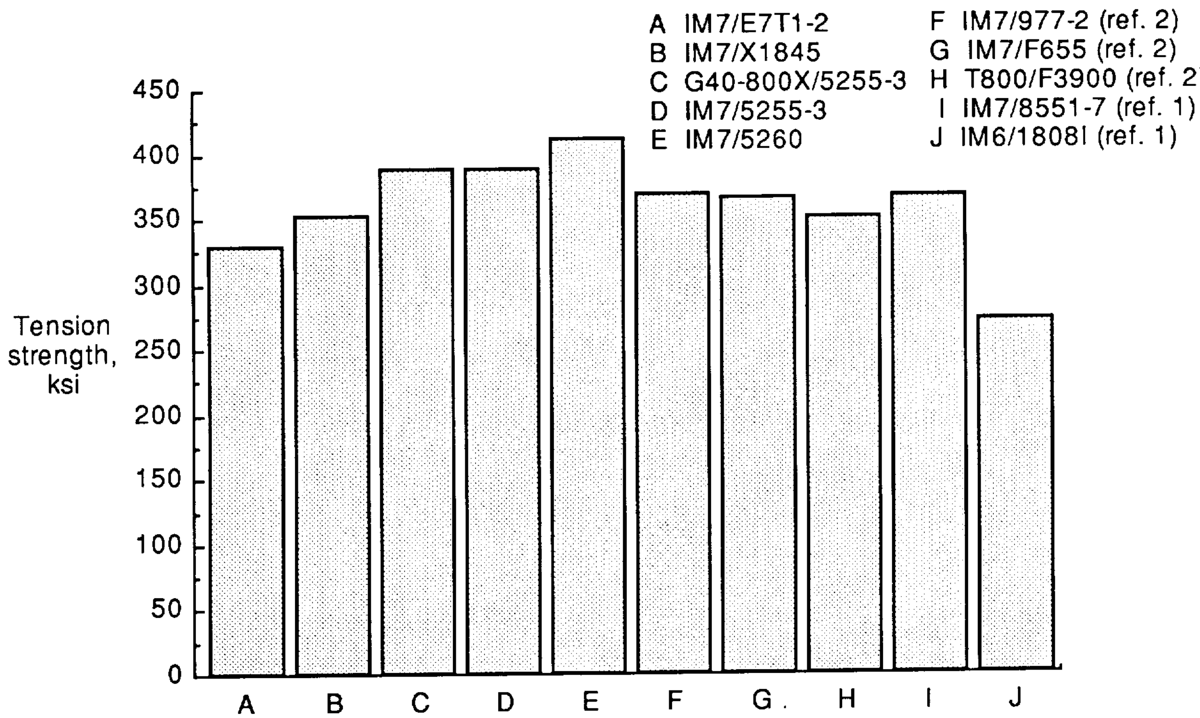


Figure 12. Typical stress-strain plots for IM7/5260 laminates.



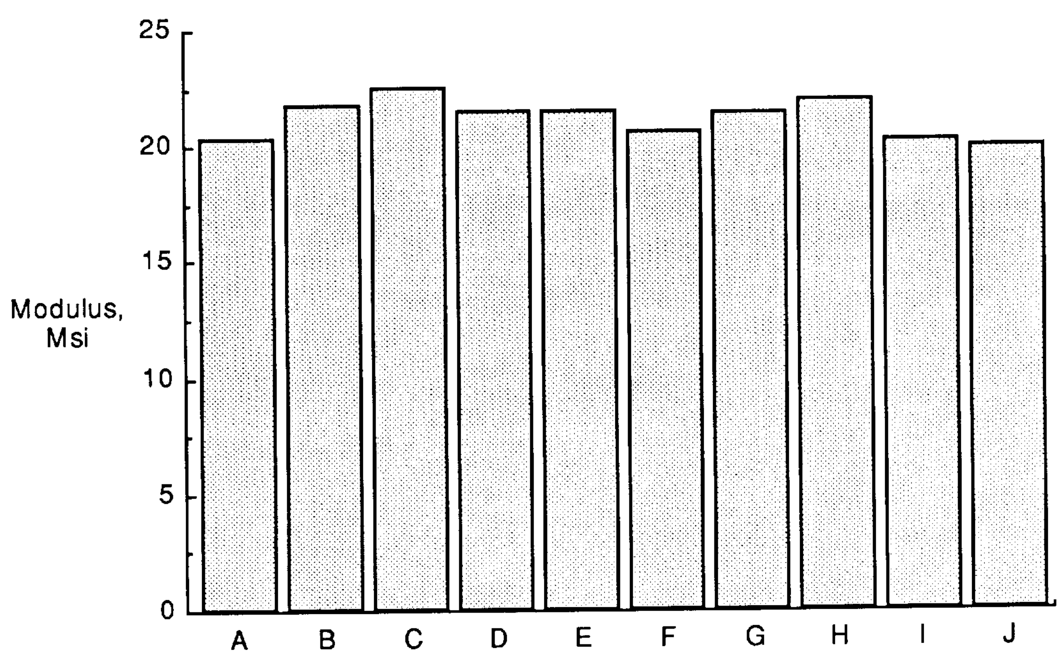


Figure 13. Tension strengths and moduli for 0° laminates.

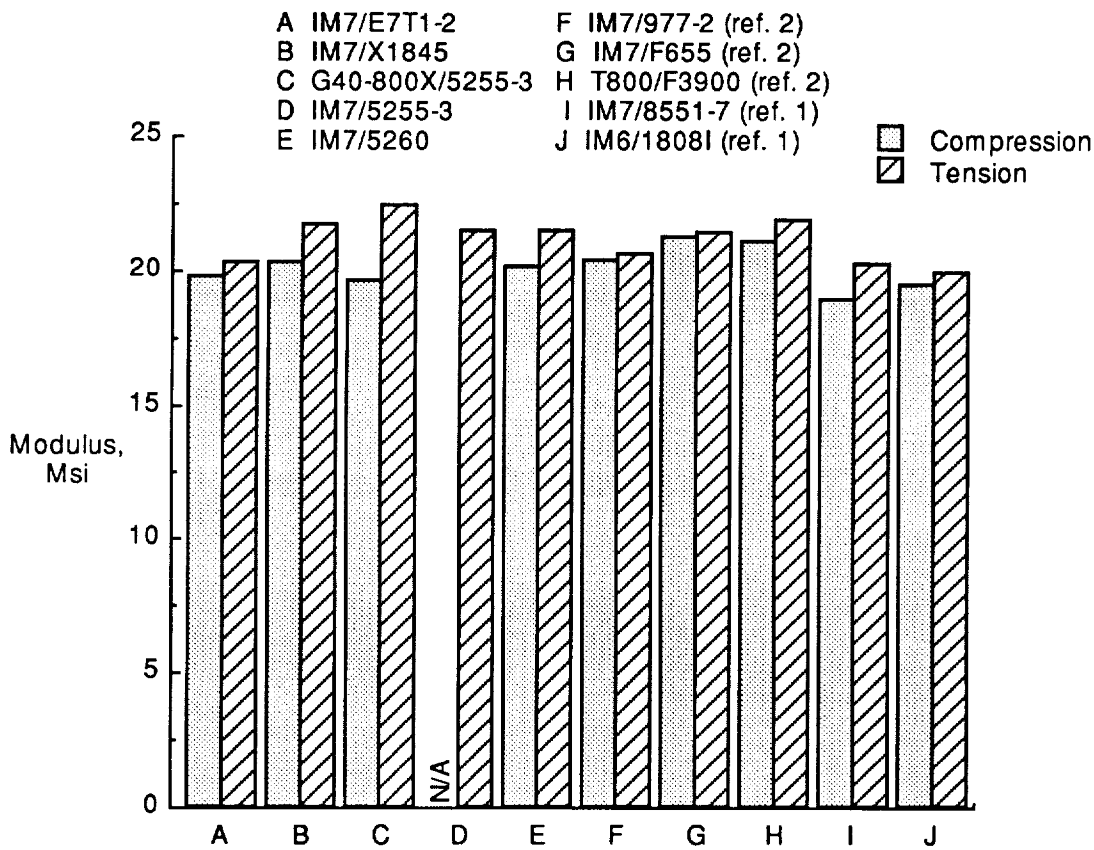


Figure 14. Compression and tension moduli for 0° laminates.

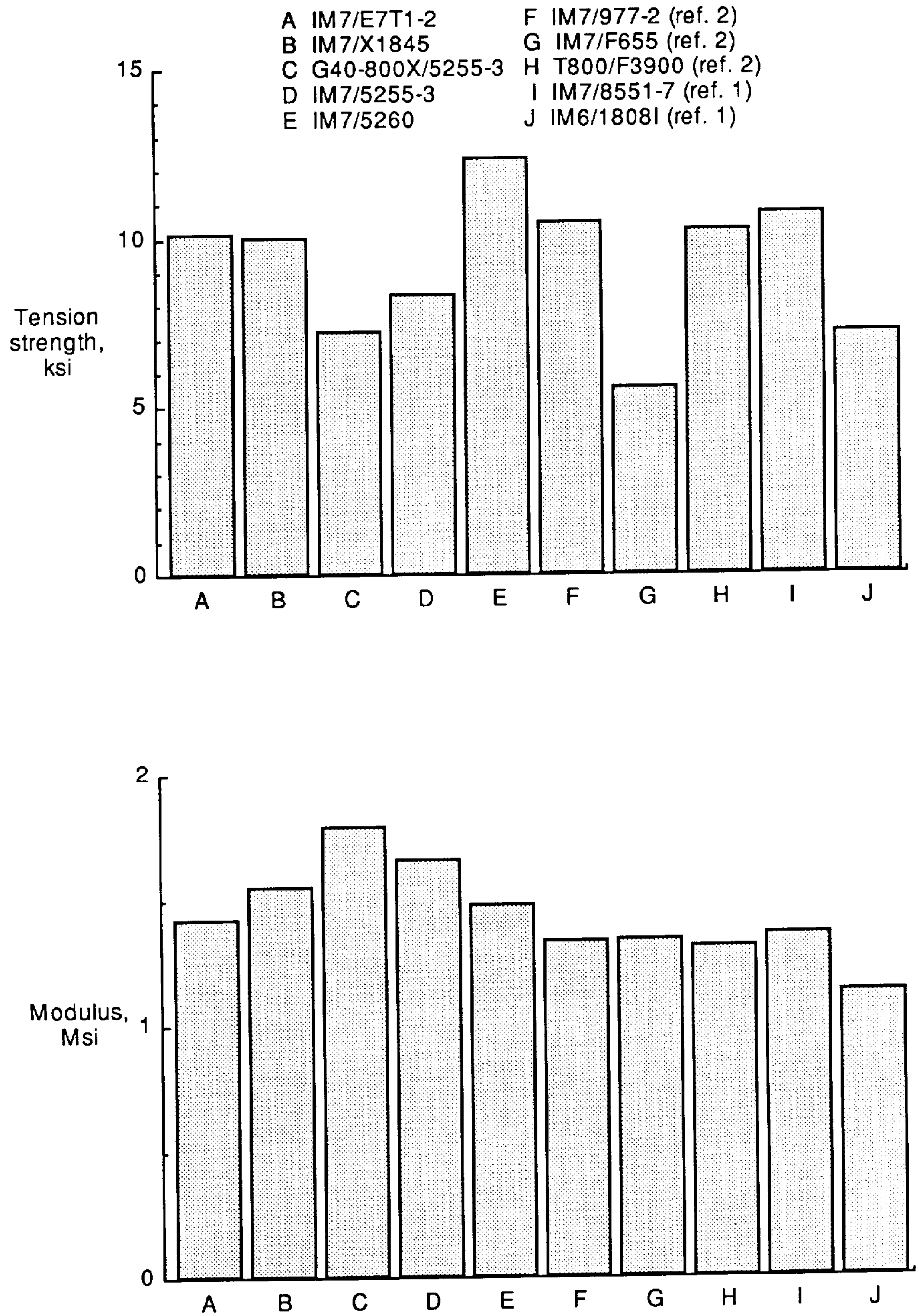


Figure 15. Tension strengths and moduli for 90° laminates.

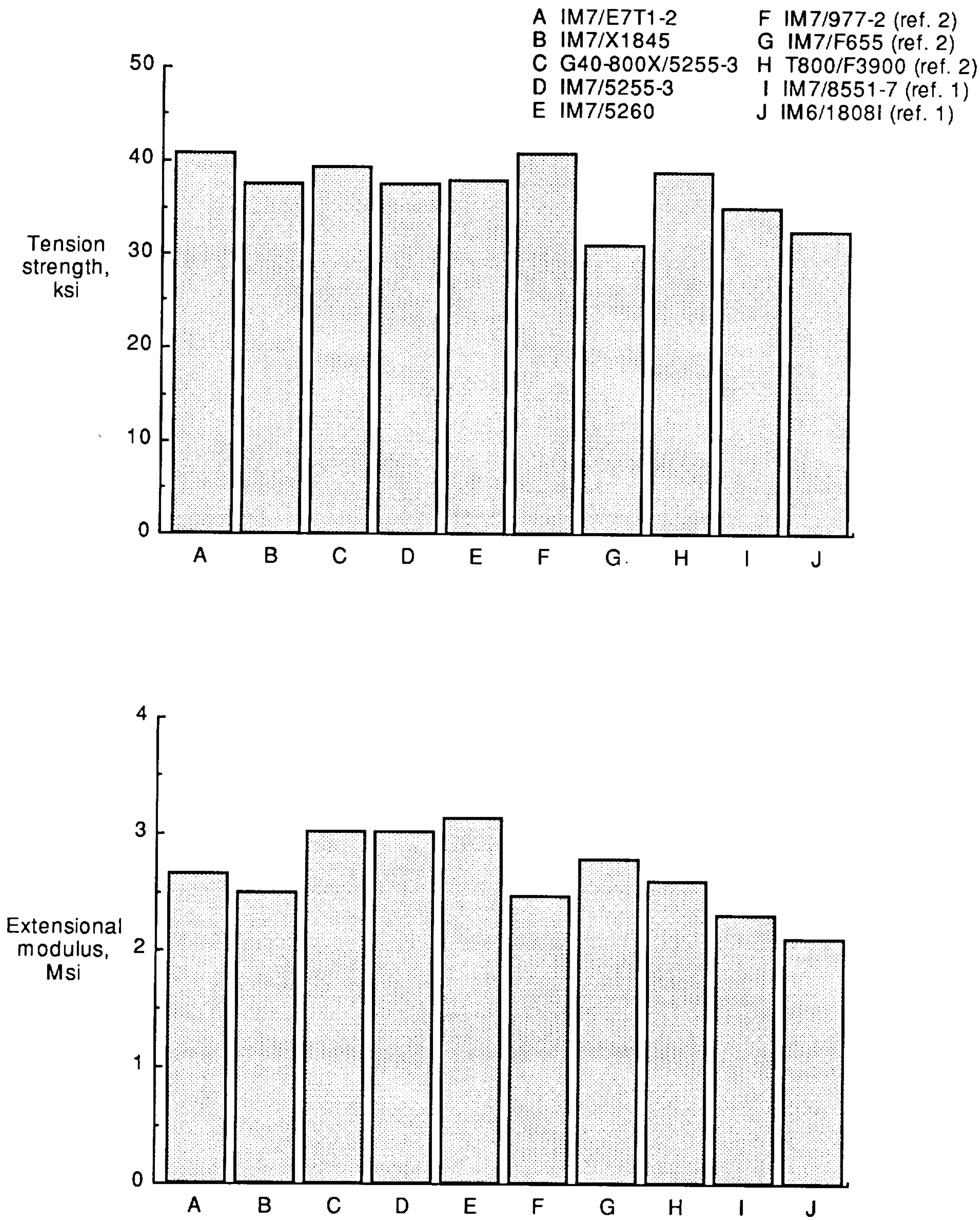


Figure 16. Tension strengths and extensional moduli for ±45° laminates.

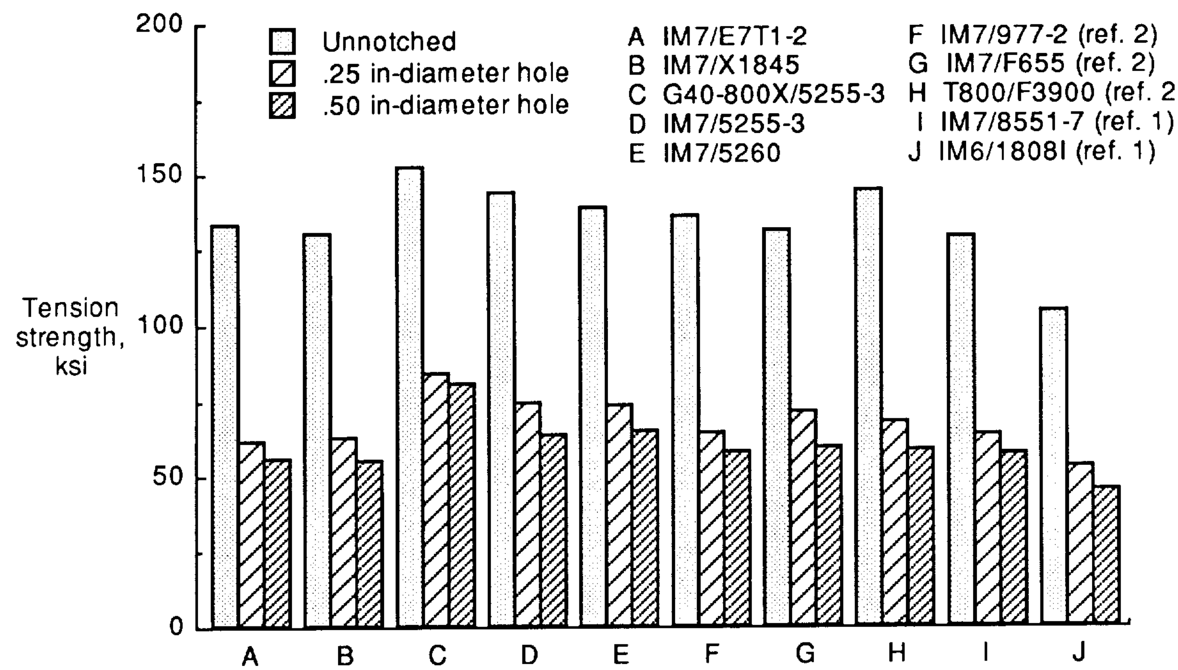


Figure 17. Tension strength for unnotched and notched (open-hole) quasi-isotropic laminates.

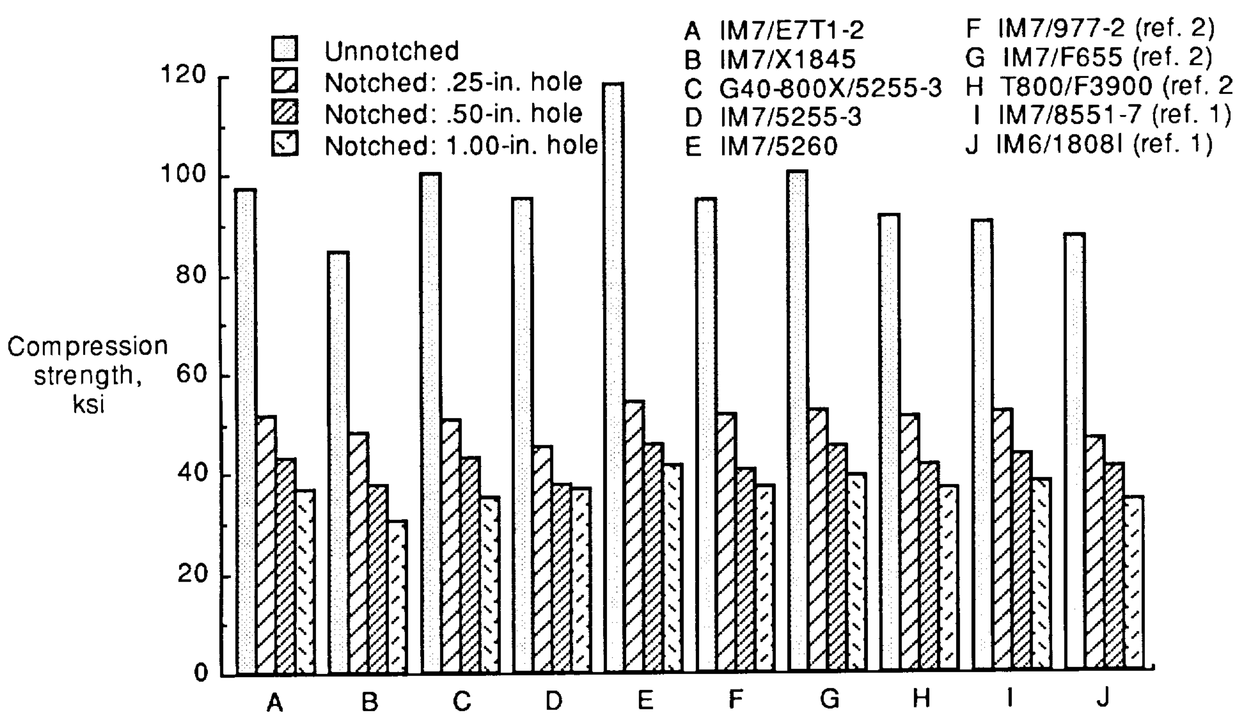


Figure 18. Compression strength for unnotched and notched (open-hole) quasi-isotropic laminates.

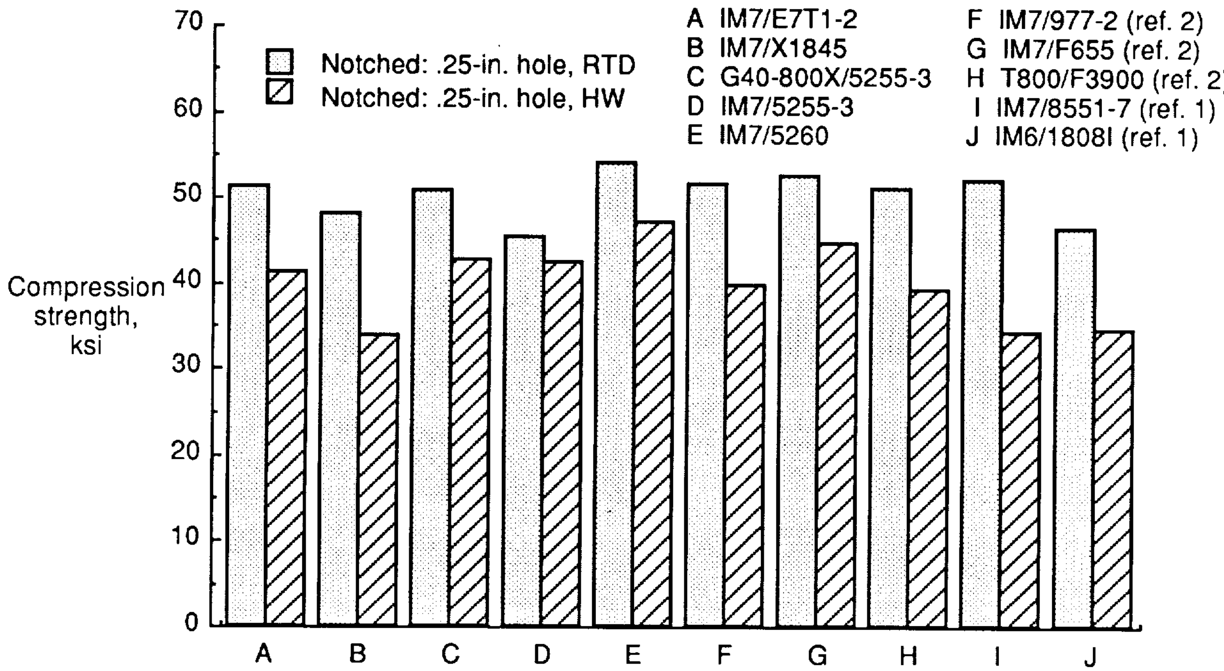


Figure 19. Compression strength for notched (open-hole) RTD and HW quasi-isotropic laminates.

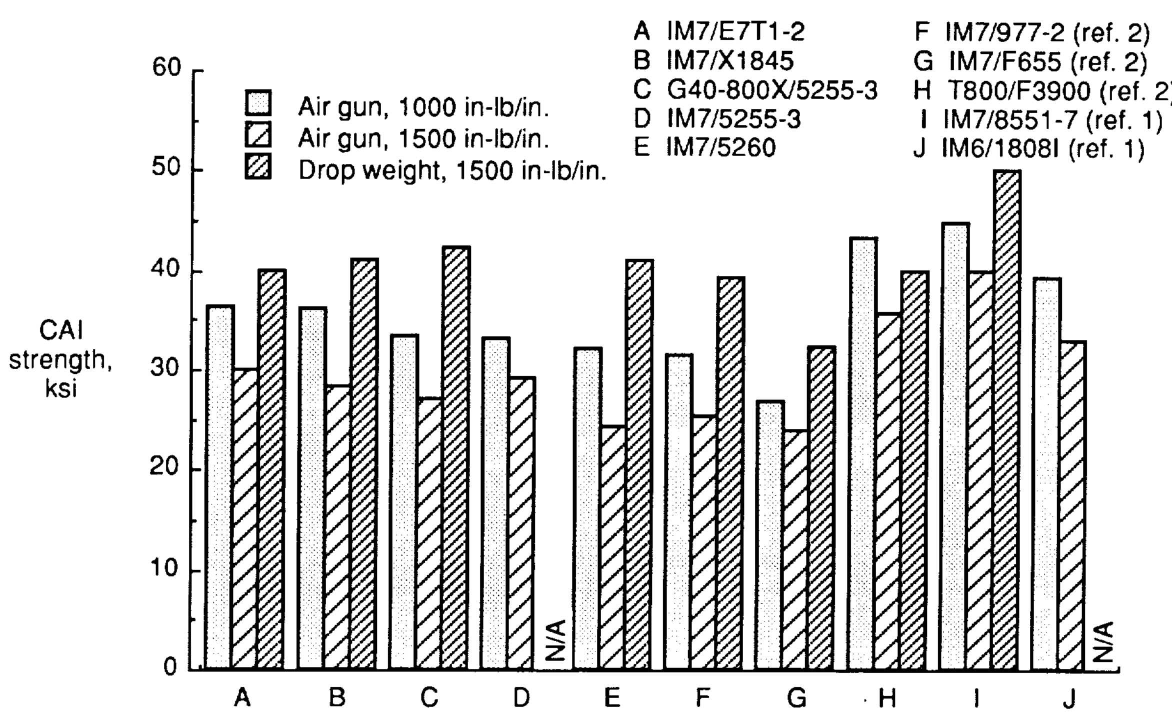


Figure 20. Compression strength for impacted quasi-isotropic laminates.

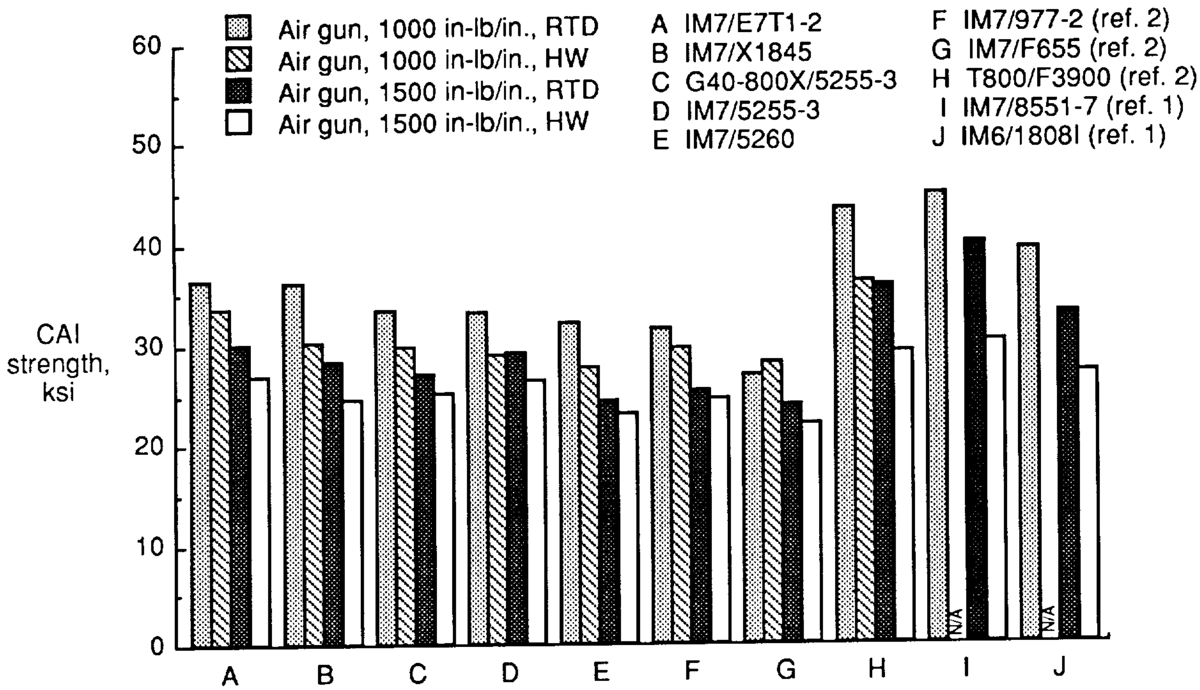


Figure 21. Compression strength for impacted RTD and HW quasi-isotropic laminates.

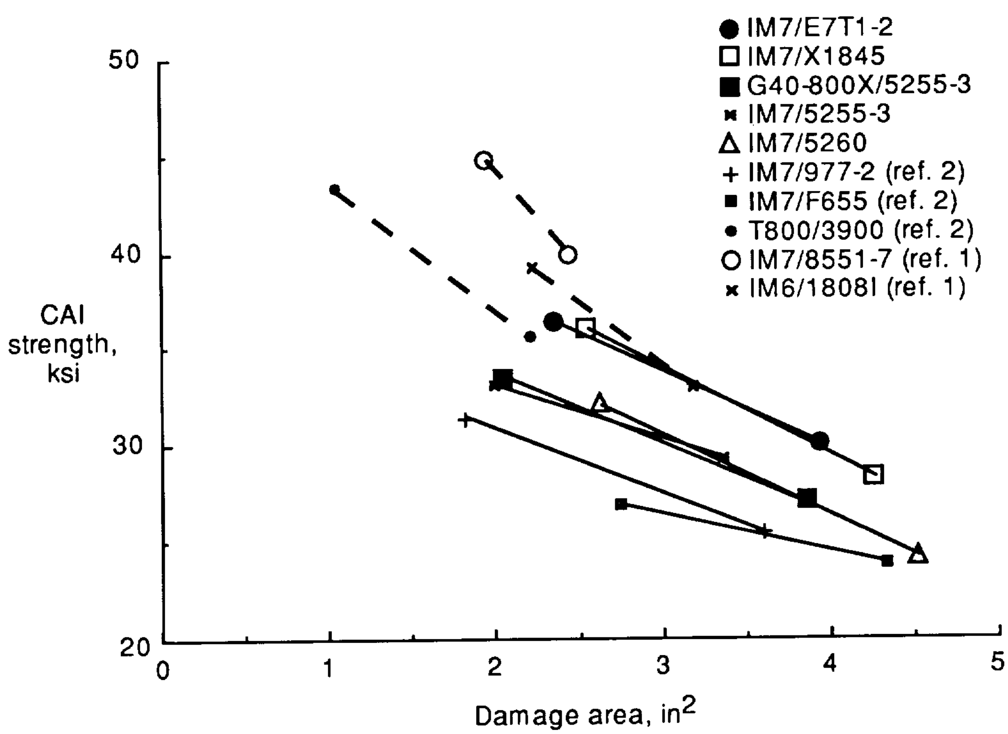


Figure 22. Damage area versus CAI strength for air-gun impacted quasi-isotropic laminates.

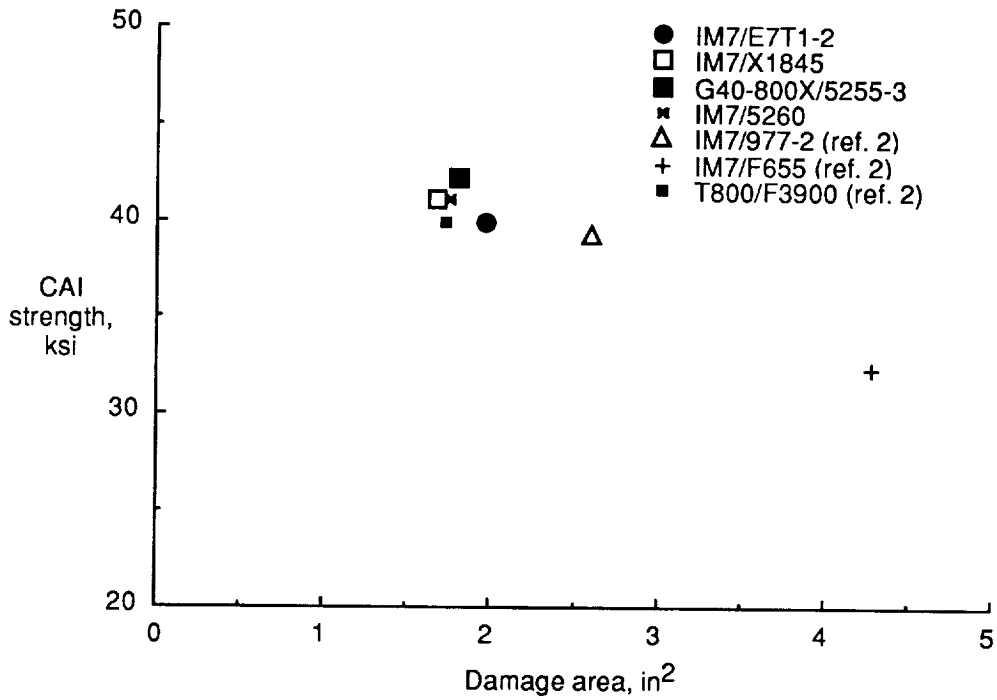


Figure 23. Damage area versus CAI strength for drop-weight impacted quasi-isotropic laminates.

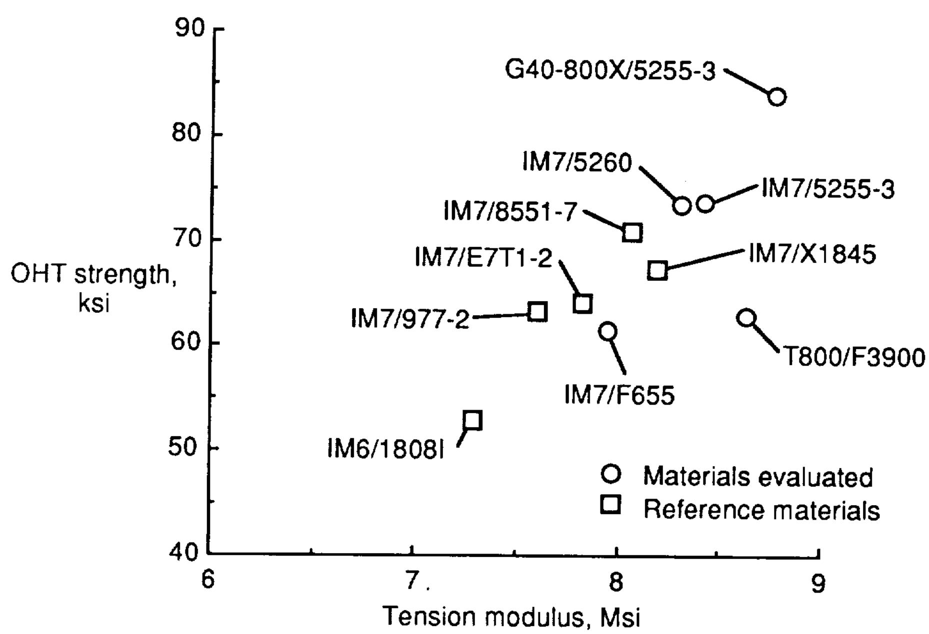


Figure 24. Tension strength (0.25-in-diameter hole) versus tension modulus.

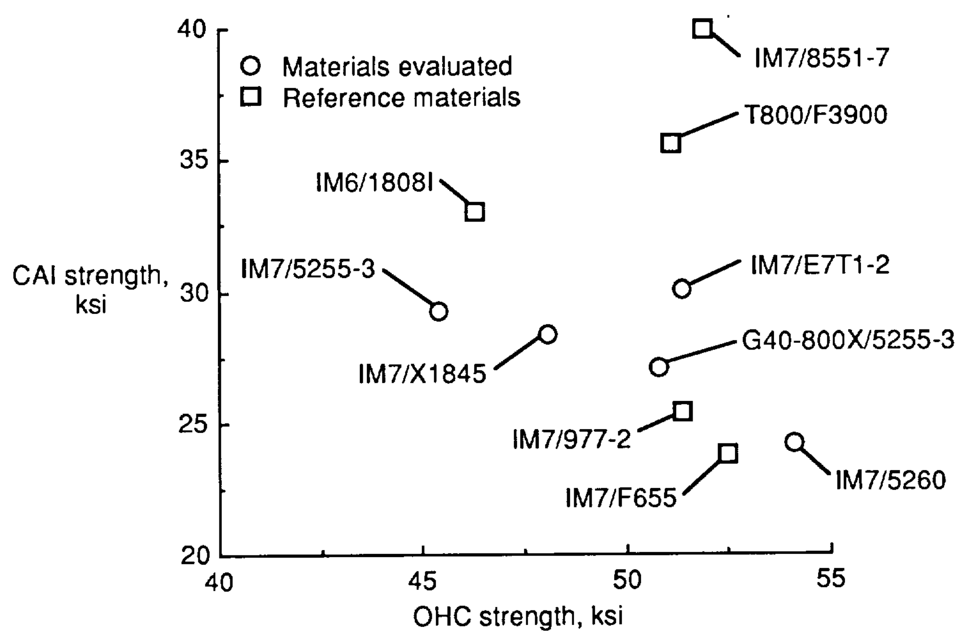


Figure 25. Compression strength comparison. Open-hole compression (0.25 in-diameter) versus compression-after-impact (1500 in-lb/in.).

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13. ABSTRACT *(Maximum 200 words)*
The use of toughened matrix composite materials offers an attractive solution to the problem of poor damage tolerance associated with advanced composite materials. In this study, the unidirectional laminate strengths and moduli, notched (open-hole) and unnotched tension and compression properties of quasi-isotropic laminates, and compression-after-impact strengths of five carbon fiber/toughened matrix composites, IM7/E7T1-2, IM7/X1845, G40-800X/5255-3, IM7/5255-3, and IM7/5260, have been evaluated. The compression-after-impact (CAI) strengths were determined primarily by impacting quasi-isotropic laminates with the NASA Langley air gun. A few CAI tests were also made with a drop-weight impactor. For a given impact energy, compression-after-impact strengths were determined to be dependent on impactor velocity. Properties and strengths for the five materials tested are compared with NASA data on other toughened matrix materials (IM7/8551-7, IM6/1808I, IM7/977-2, IM7/F655, and T800/F3900). This investigation found that all five materials were stronger and more impact damage tolerant than more brittle carbon/epoxy composite materials currently used in aircraft structures.

14. SUBJECT TERMS
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